Intercontinental Transport of Ozone and Precursors (ITOP)

Ally Lewis, Ruth Purvis, Jim Hopkins, James Lee, Nicola Watson
Department of Chemistry, University of York
Mike Pilling, Dwayne Heard, Trevor Ingham, Lisa Whalley, Cedric Floquet,
Department of Chemistry, University of Leeds
Steve Arnold, Mat Evans, Jim McQuaid, Dominick Spracklen, Kirsty Pringle
School of the Environment, University of Leeds
Paul Monks, Mark Jacob, Alex Parker
Department of Chemistry, University of Leicester
Stuart Penkett, Claire Reeves, Graham Mills, David Oram, Brian Bandy, Debbie Wylding, Jana Slemr, Dave Stewart, Anne Hulse
School of Environmental Sciences, University of East Anglia
Hugh Coe, Paul Williams, Jonny Crozier, Rami Alfarra
Department of Physics, UMIST
John Methven
Department of Meteorology, University of Reading
John Pyle, Rod Jones, Will Flynn, James Levine, Peter Cook
Department of Chemistry, University of Cambridge
John Reid, Ken Dewey, Nick Price, Steve Devereux, Doug Anderson
Facility for Airborne Atmospheric Measurements
Alan Foster, Alan Roberts, Gaynor Ottoway, Peter Chappell
DirectFlight Ltd
Martin Darling, Andrew 'Rodders' Boardman, Simon Tooley
Avalon Aero Ltd

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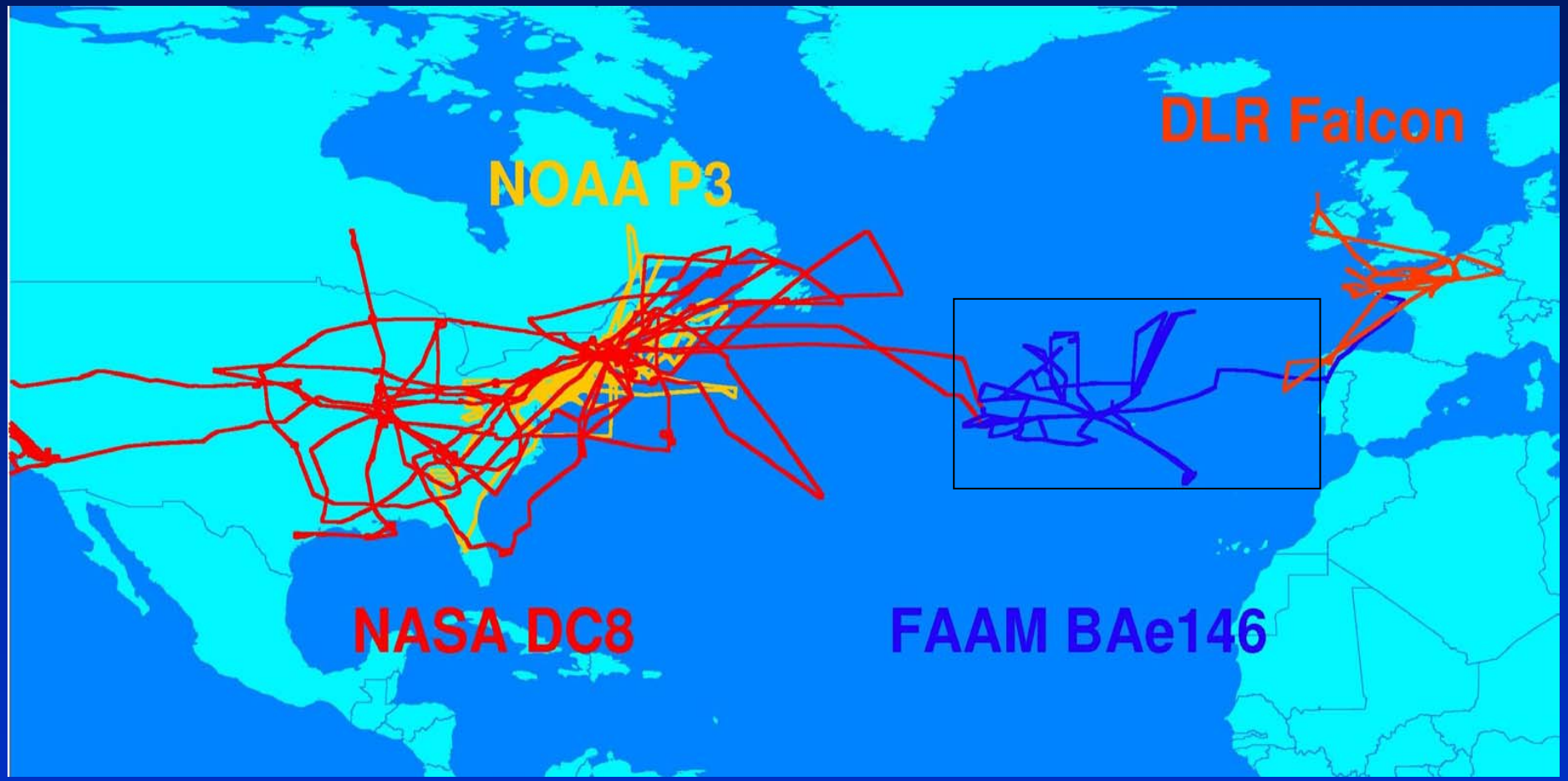
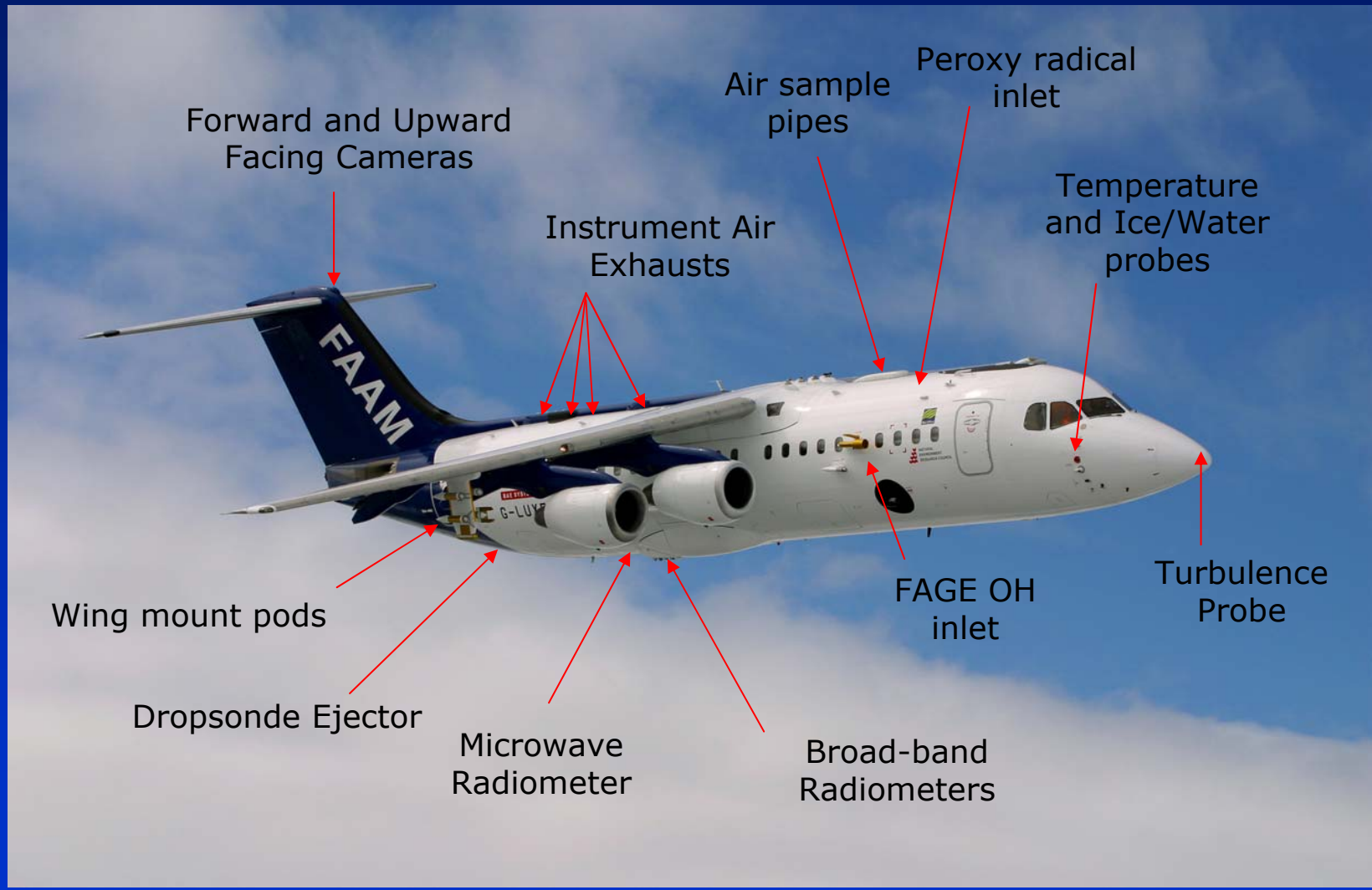
ICARRT Summer 2004



FAAM BAe146, based in Faial, Azores, flew 12 science flights ~70 hours including intercomparison flights with DLR Falcon and NASA DC8

The Facility for Airborne Atmospheric Measurements BAe-146 Research Aircraft



Flight Highlights

- Three-point Lagrangian opportunities: 19/7 + 25/7
  28/7 + 29/7 and 31/7 + 1/8.
- Two-point Lagrangian opportunities: 17/7, 20/7 (fire).
- Forest fires: 15/7, 19/7, 20/7, 31/7 (with strat), 1/8.
- Pico flypass: 15/7, 17/7, 19/7, 31/7, 1/8.
- Comparisons: 28/7 (DC8), 3/8 (Falcon).
- ENVISAT underpass: 22/7.

B028 – 12/7/04 – Fire plumes in SW approaches

B029 – 15/7/04 – W to E Low level pollution + forest fires

B030 – 17/7/04 – First Lagrangian opportunity, - skimmed P3 air

B031 – 19/7/04 – New York plume + fire layers

B032 – 20/7/04 – Dominated by Alaskan fires, low T

B033 – 22/7/04 – ENVISAT underpass / cyclone

B034 – 25/7/04 – Re interception of NY plume + African outflow

B035 – 28/7/04 – DC8 comparison / air exported by wcb

B036 – 29/7/04 – Upper level export in wcb from US + fires higher T

B037 – 31/7/04 – low level wcb sampled by P3, + fires + strat

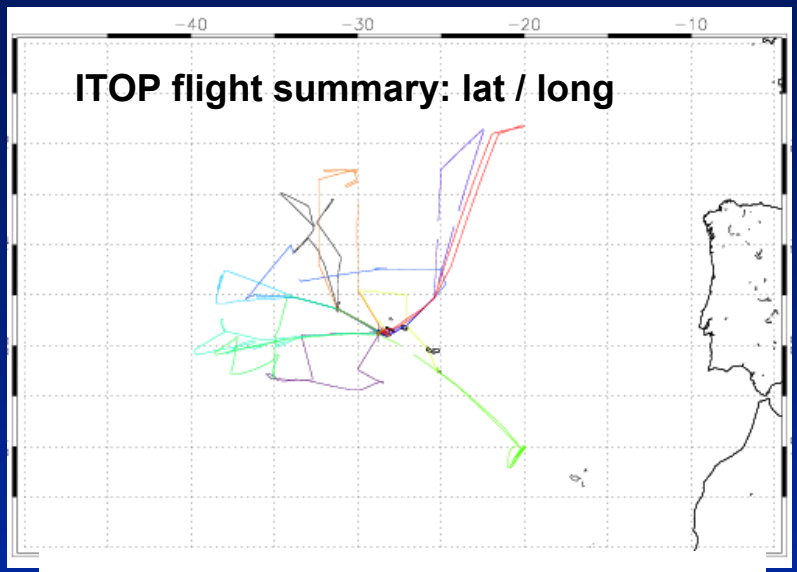
B038 – 01/8/04 – low level wcb 2

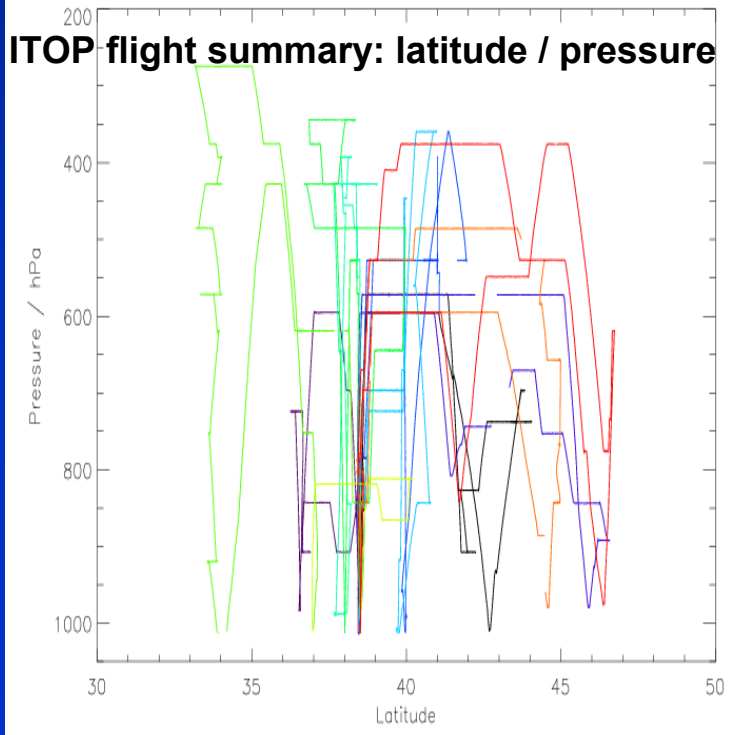
B039 – 03/8/04 – Transit / Falcon intercomparison

ITOP data coverage

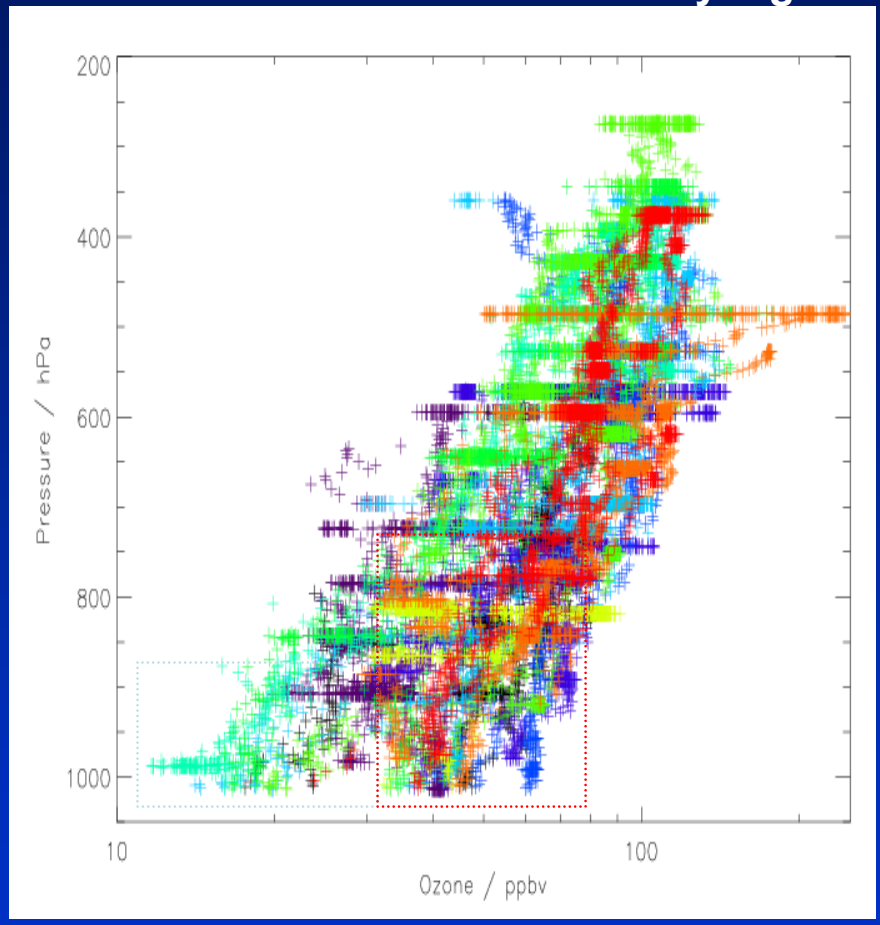
	B028	B029	B030	B031	B032	B033	B034	B035	B036	B037	B038	B039
Core data	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
CO	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
O_3	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
NO	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
NO_2	N	N	N	?	?	?	?	?	?	?	?	?
NOy	?	?	?	?	?	?	?	?	?	?	?	?
HCHO	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N
H_2O_2	N	N	Y	Y	N	Y	Y	N	Y	Y	N	N
PTR-MS	N	N	N	N	N	N	N	Y	Y	N	N	N
alkyl nitrates	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
Halocarbons	N	N	N	N	N	N	N	N	N	N	N	Y
PAN	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
WAS VOCs	26	60	58	61	48	52	59	32	48	61	62	34
OH/HO_2	N	N	N	N	N	N	N	N	N	N	N	N
radiometers	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
PERCA	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
AMS	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
CPC	N	N	Y	Y	Y	Y	N	Y	Y	Y	Y	Y

Overview of U.K. activities





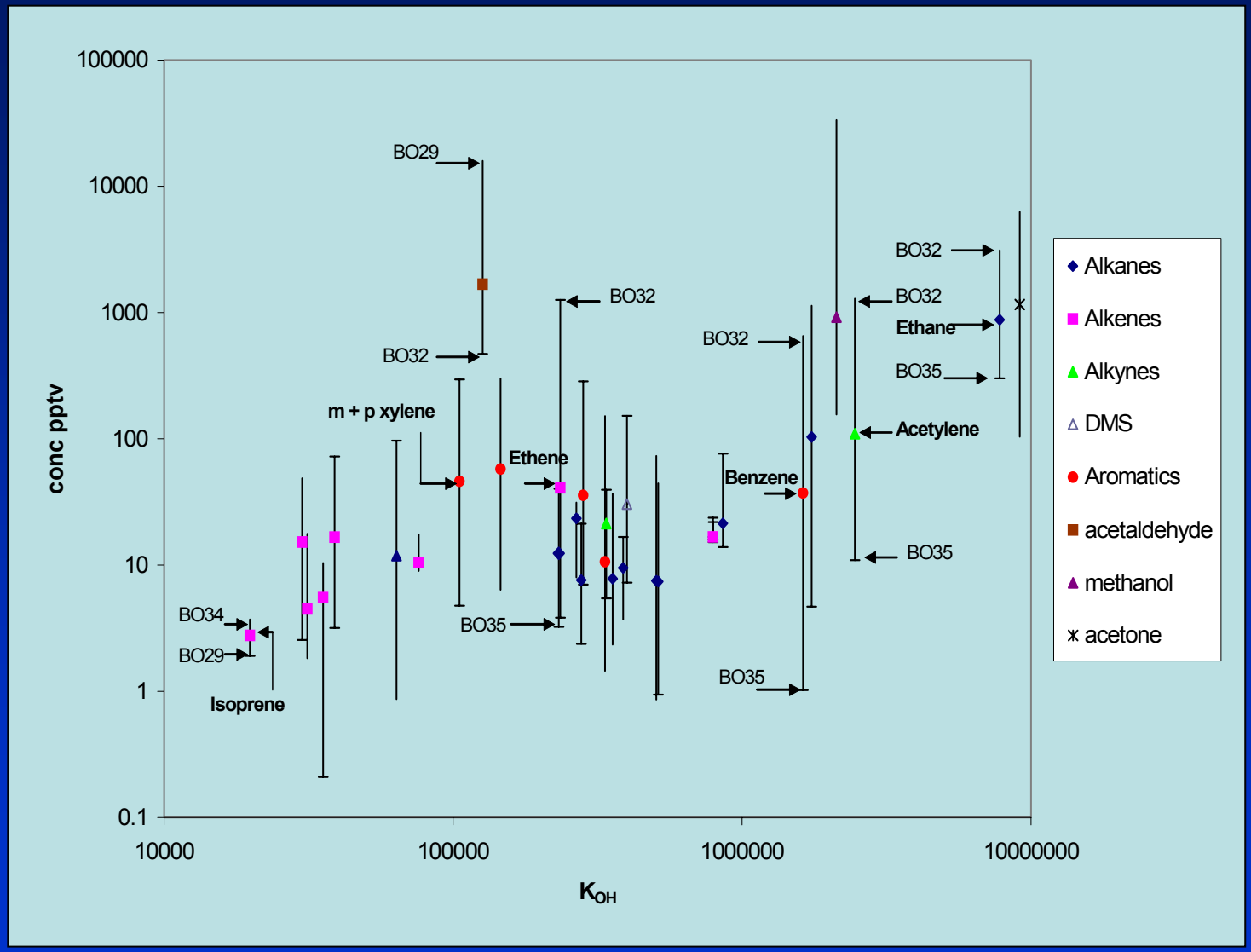
Complete ITOP campaign ozone as a function of altitude. Coloured by flight.



Clean MBL / 15 ppb

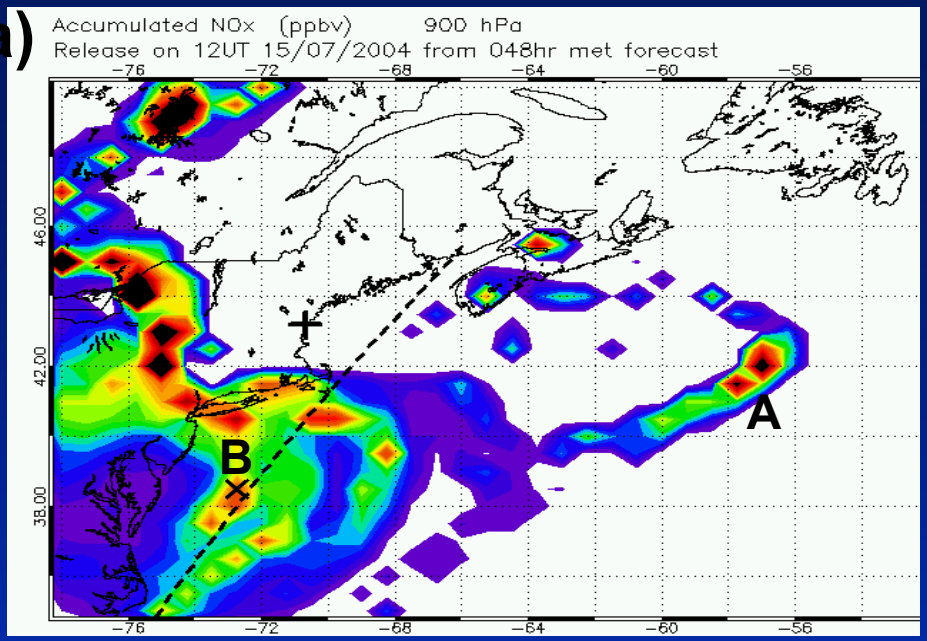
Significant long range continental influence at both low and high altitudes during campaign

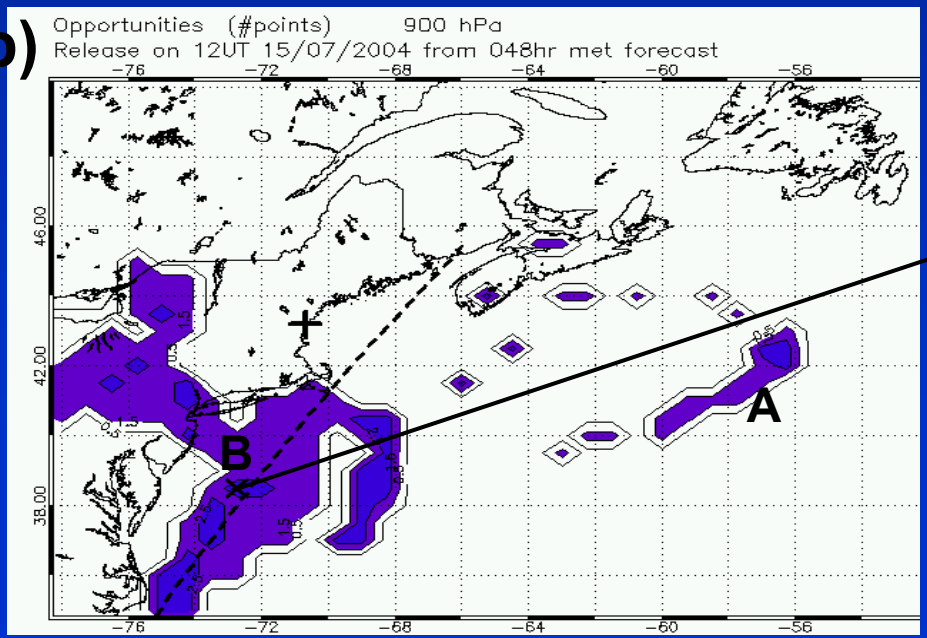
NMHC variability – campaign overview



B029 / 32 fire dominated, B035 DC8 comparison

Forecasting target for upstream domain



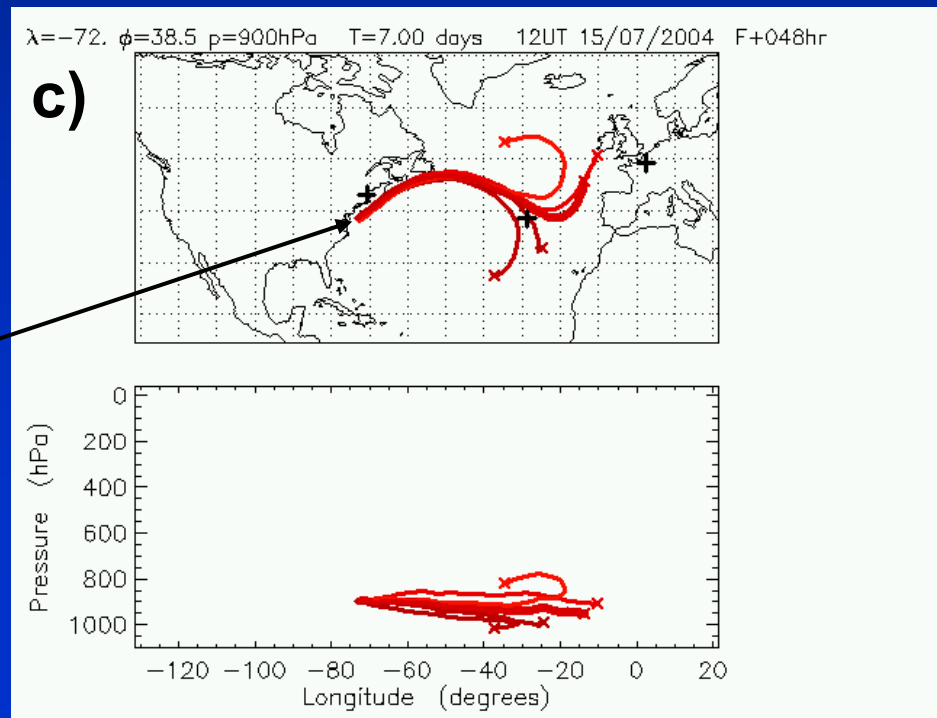


Domain filling trajectory forecasts for E.Coast America domain on 15 July.

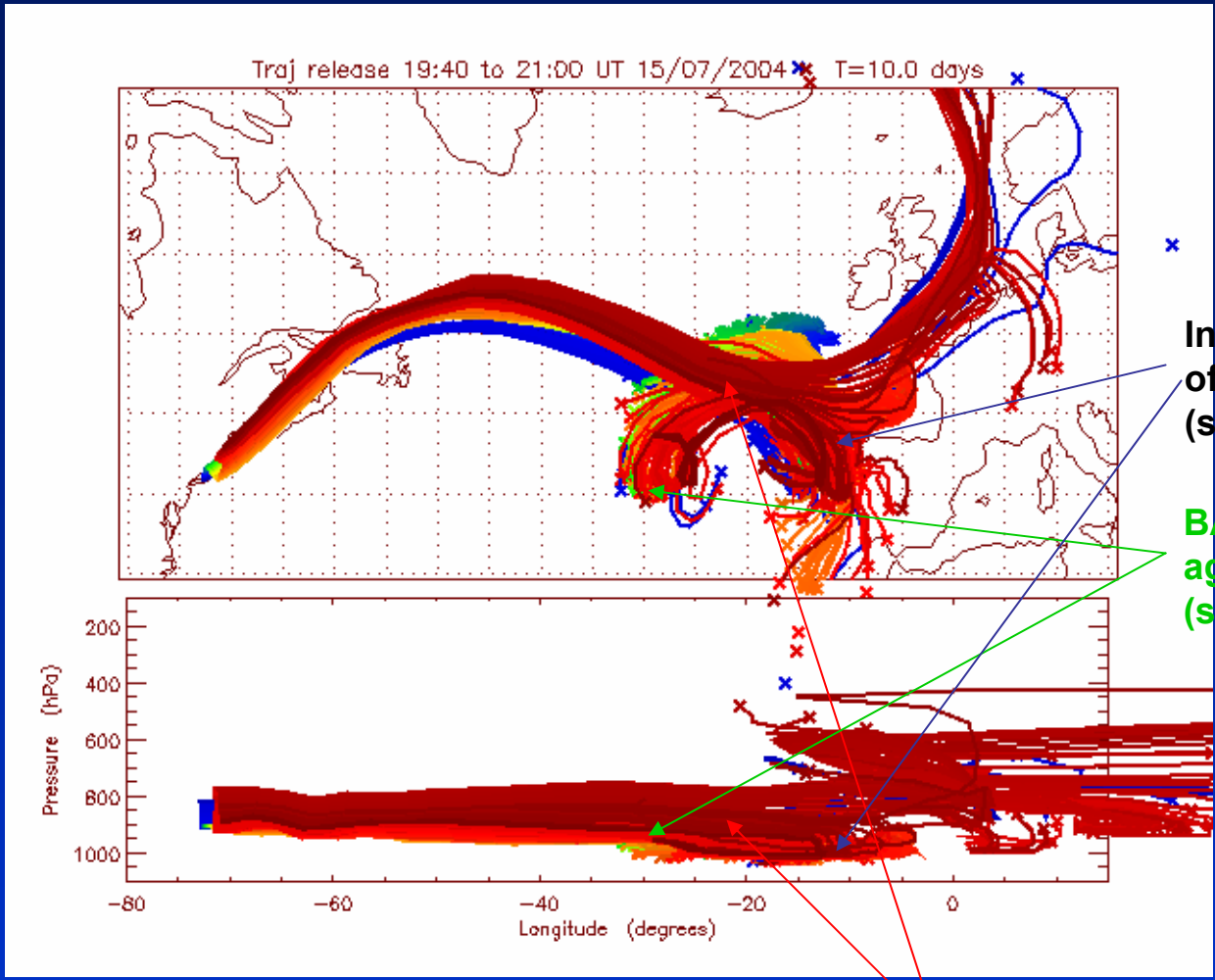
a) NOx emissions tracer at 900 hPa

b) 2-point and 3-point opportunities highlight targets A and B.

c) 7 days forward from target B



Forward Trajectories from NOAA P3 flight track



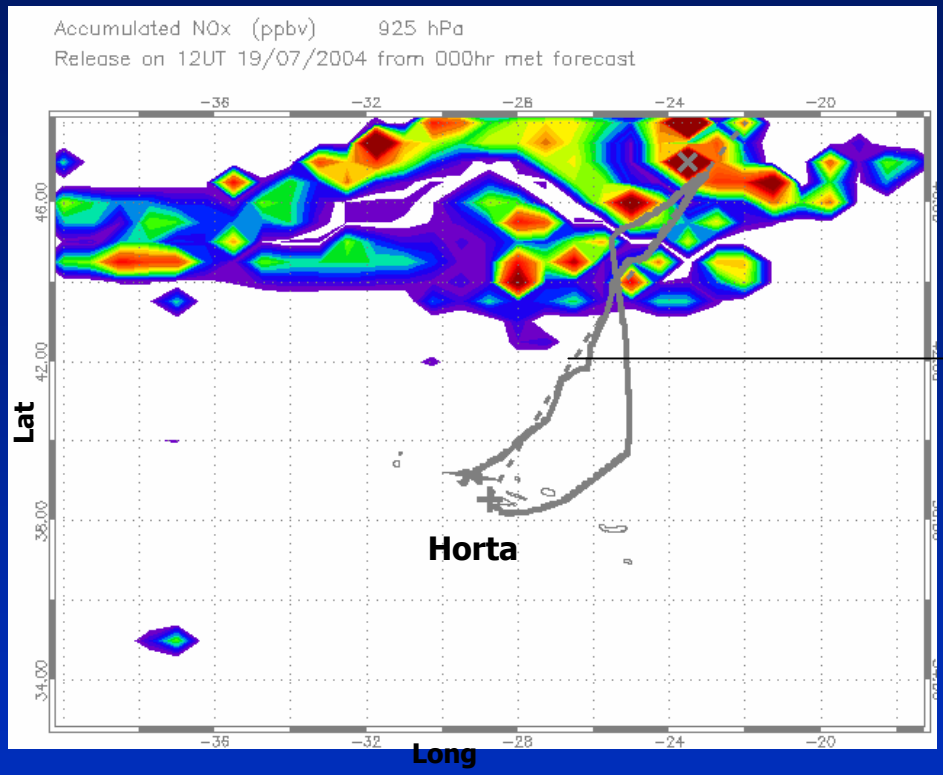
Intercepted by DLR Falcon off NW corner of Spain on 22/7 (saw CO ~ 90-100ppb).

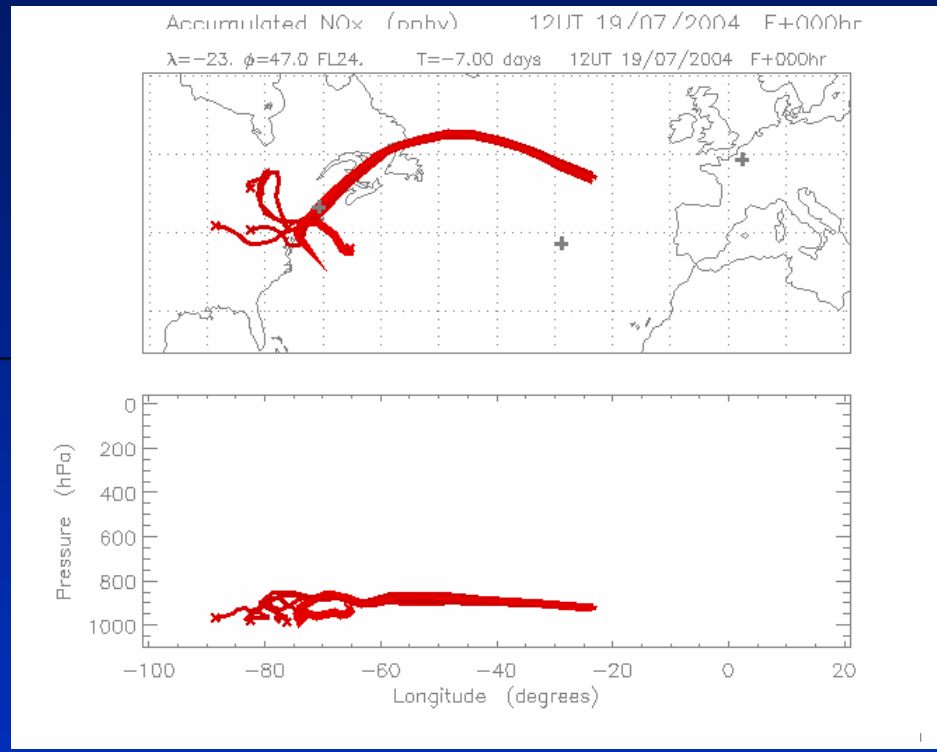
BAE146 flight intercepted this air again on 25/7 (saw increased CO ~ 115-125ppb).

10 day forward trajectories from NOAA P3 flight off NYC on **15/7**. Airmass doubles back from Spain to the Azores.

BAE146 flight intercepted this air on 19/7 (saw CO ~ 115-125ppb).

Analysis: Second interception of polluted airmass from USA



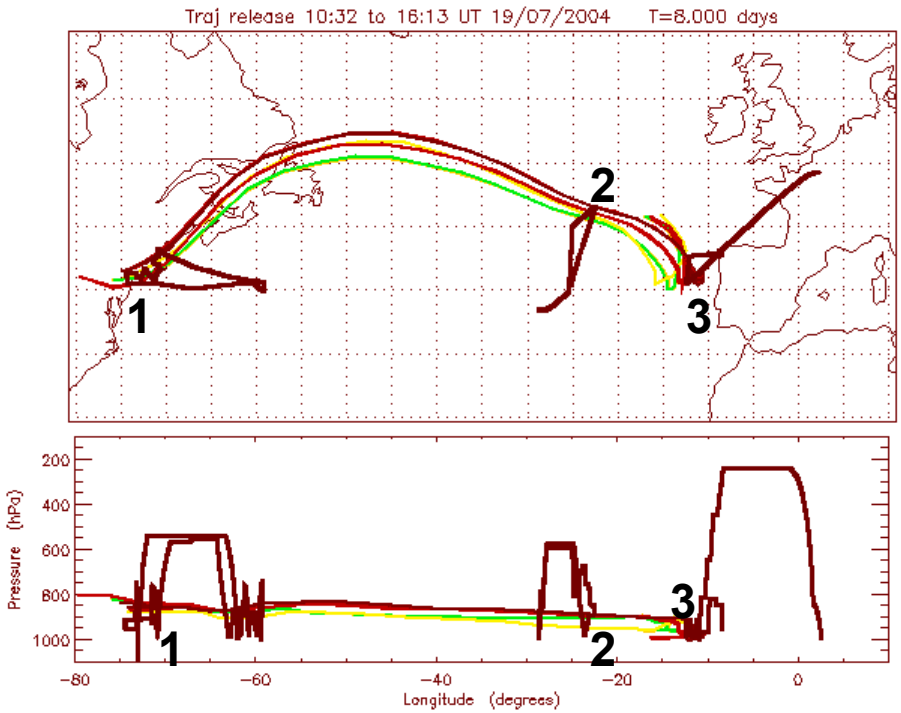


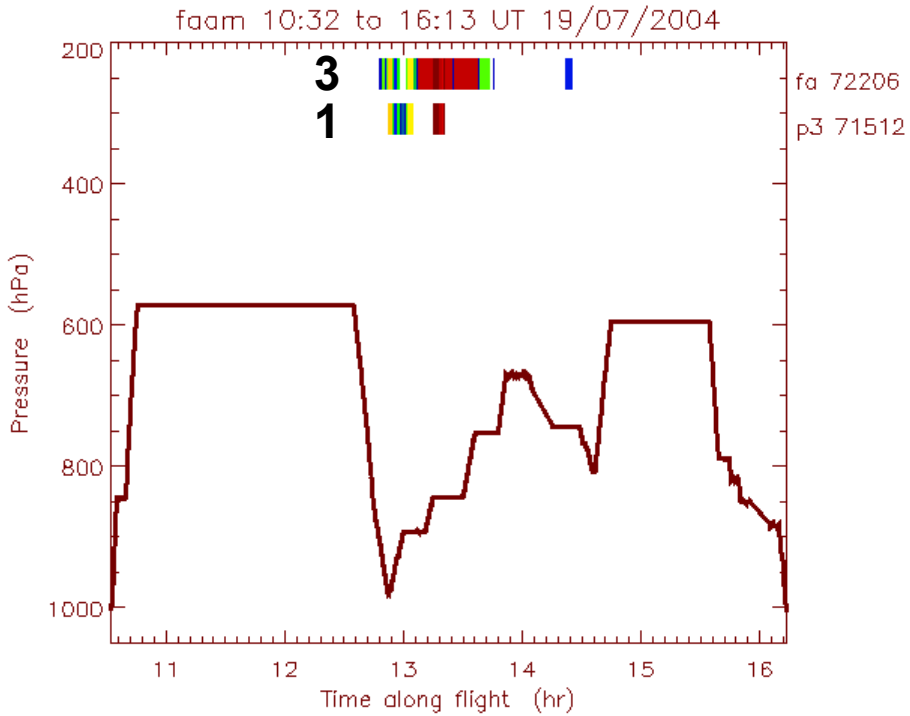
• NOx emissions tracer on 925hPa at 12UT 19/7 with BAE146 (air mass relative) flight track overlaid.

• Indicates high emissions into low level outflow from East Coast USA.

Back trajectories from target X confirm NYC as being air mass origin

Did the aircraft make the interception?





Trajectories from BAe146 flight track back and forwards for 4 days.

Best matches with trajectories from other flight tracks.

Time series along flight track.

Line shows pressure and colour bars mark air masses intercepted on other flights.

Was the Quasi-Lagrangian expt successful?

- Trajectories based on analyses show that downstream aircraft flew very close to air masses already sampled upstream.

  But, can it be regarded as the same air mass?

1. Do hydrocarbon fingerprints agree *(using ratios to acetylene to allow for mixing and dilution with surrounding air)*?

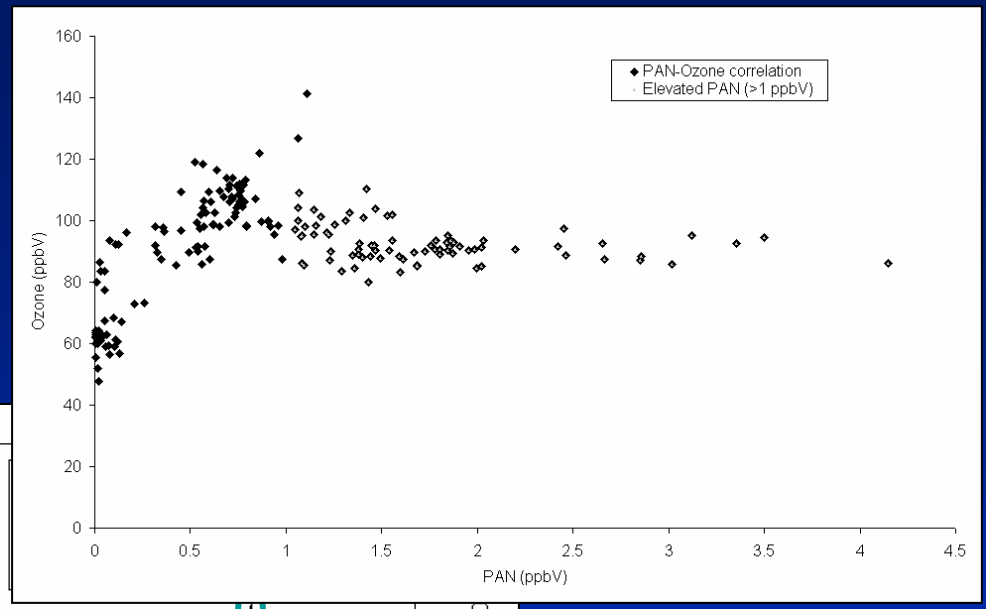
2. Is observed $\Delta O_3(\tau)$ > instrumental error *(comparison flights)*?
   > uncertainty in value at origins, $O_3(t_0 - \tau)$?

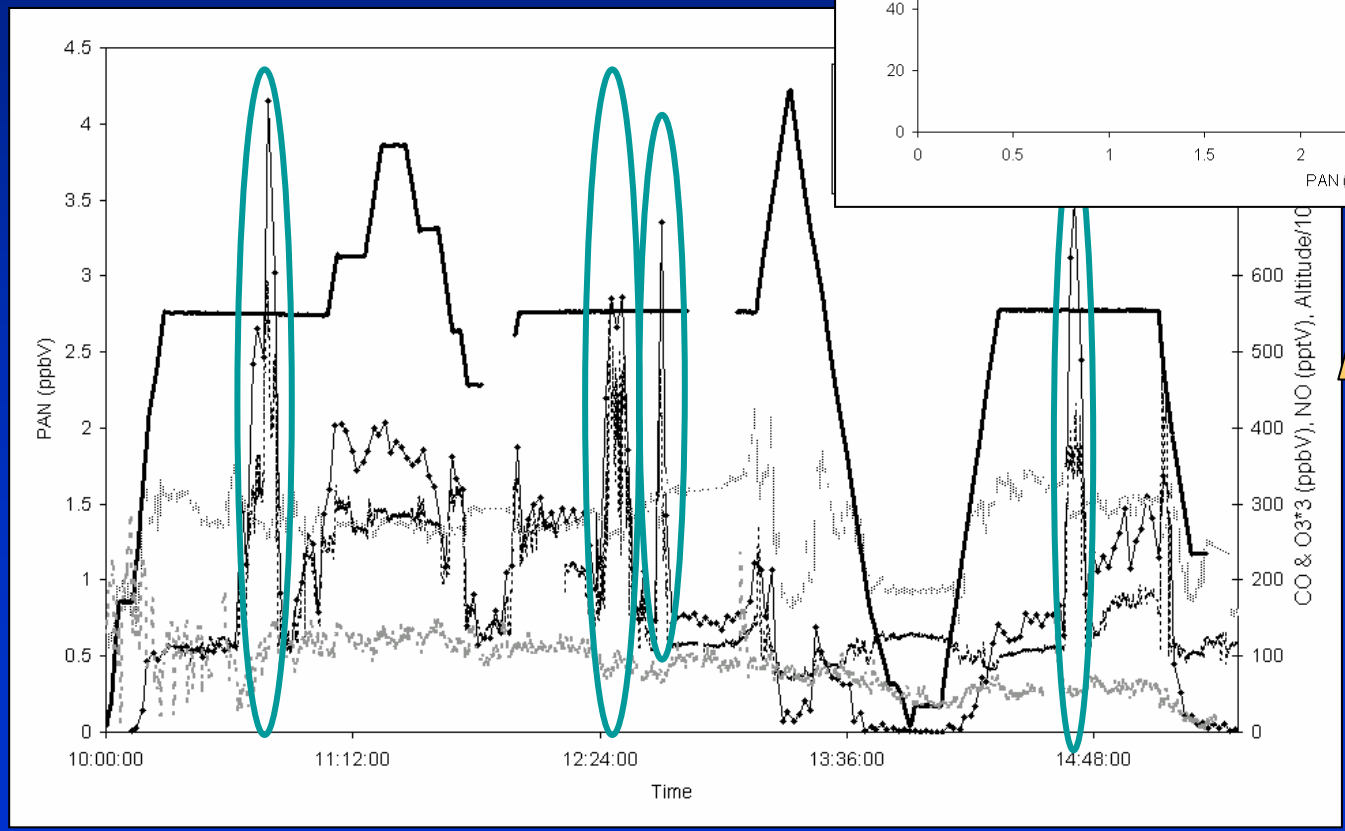
3. What is the sensitivity of ΔO_3 to initial conditions, reaction pathways, mixing history, …?

Alaskan Biomass Plumes: B032

PAN & CO were extremely elevated within the plume and displayed a strong, positive correlation

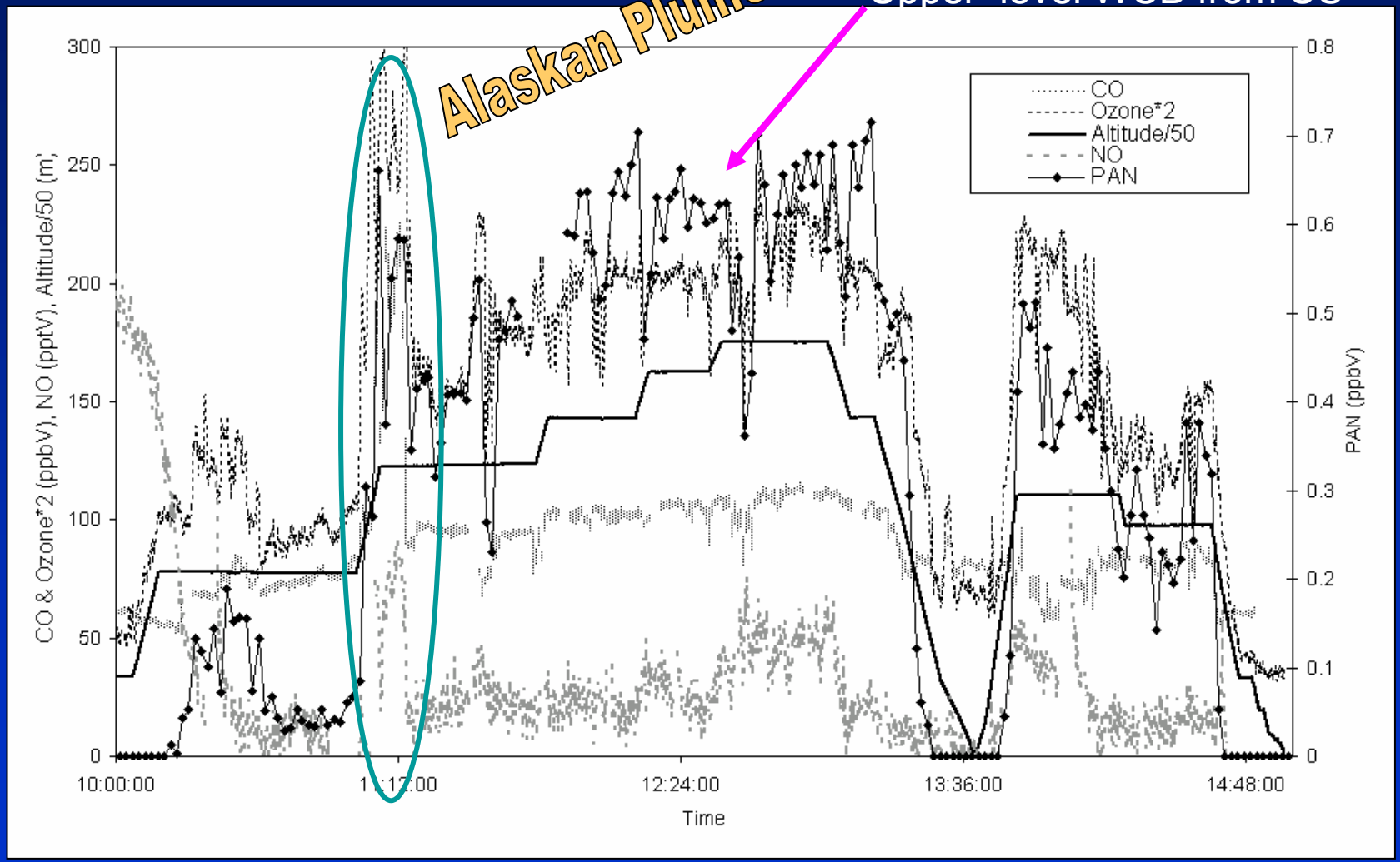
Ozone seemed somewhat suppressed within the plume





Alaskan biomass plume was extensively sampled at 5.6 km

In Contrast...B036



Plume Comparison

	B032 Plume	B036 Plume
PAN	1.72 ppbV	0.43 ppbV
O_3	92 ppbV	133 ppbV
CO	261.2 ppbV	132.8 ppbV
(PAN/NOy)*100	39 %	15 %
Temperature	263.4 K	268.0 K

Work in progress

Lagrangian matching using tracers + trajectories. (*Reading / Leeds / York*)

PAN / ozone model studies. (*Leeds / York*)

3D model diagnostics of ozone (*Cambridge*)

Box model / trajectory calculations of o-VOC production (*Leeds*)

HOx determinants (*Leeds*)

Aerosol composition analysis (*Manchester*)

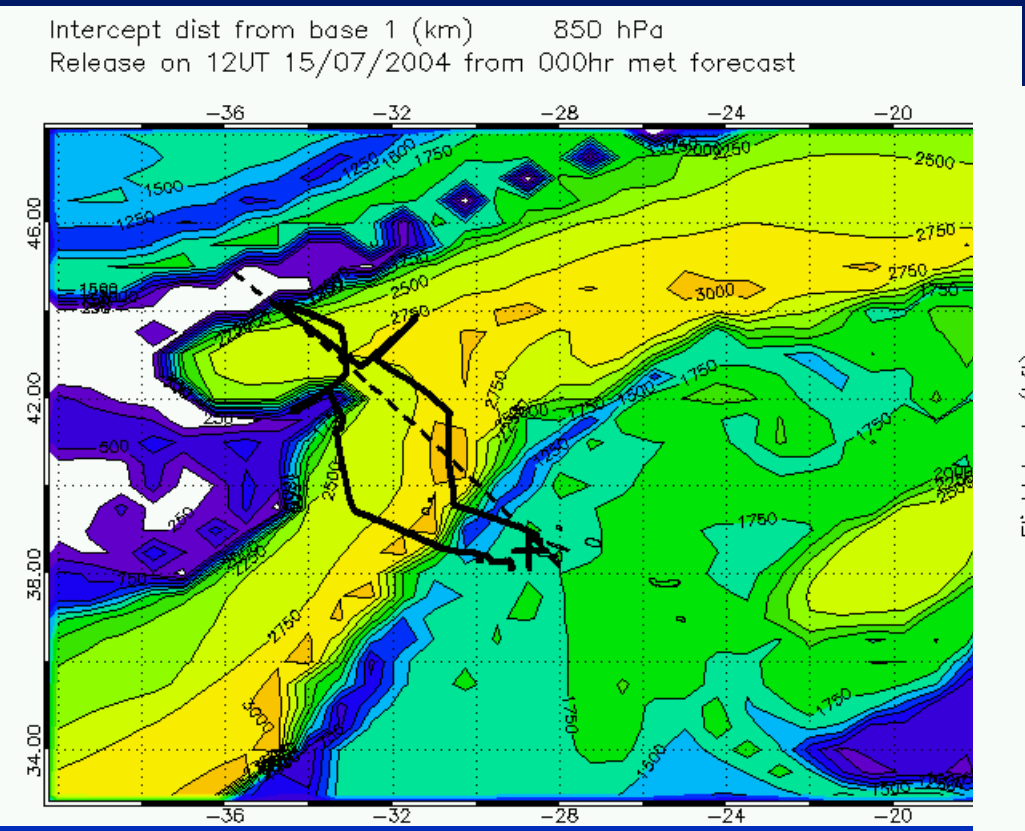
Lagrangian model to investigate sensitivity of trans-Atlantic ΔO_3 to:

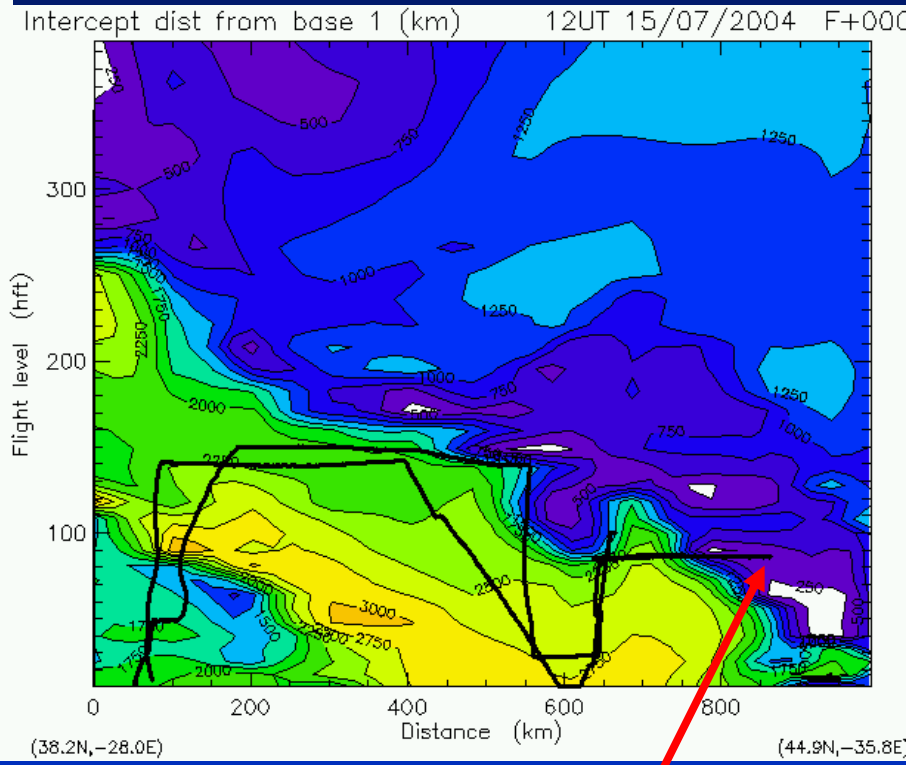
- ***Mixing rate***
- ***Cloud cover***
- ***ECMWF water vapour***
- ***NMHC complexity***
- ***Initial conditions***

- **Constraint of mixing term through hydrocarbons.**
- **Full Monte-Carlo analysis using Lagrangian model.**
- **Can reduced chemical mechanisms describe the observed change in composition or is complexity unavoidable?**

UK ITOP flight by flight summary

B029: 15/07/04 Low level pollution and fires

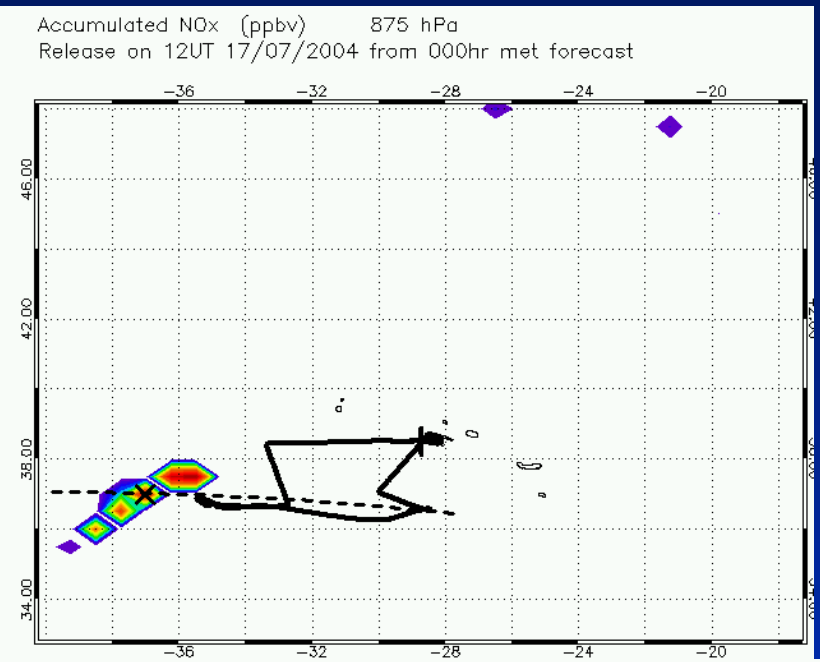


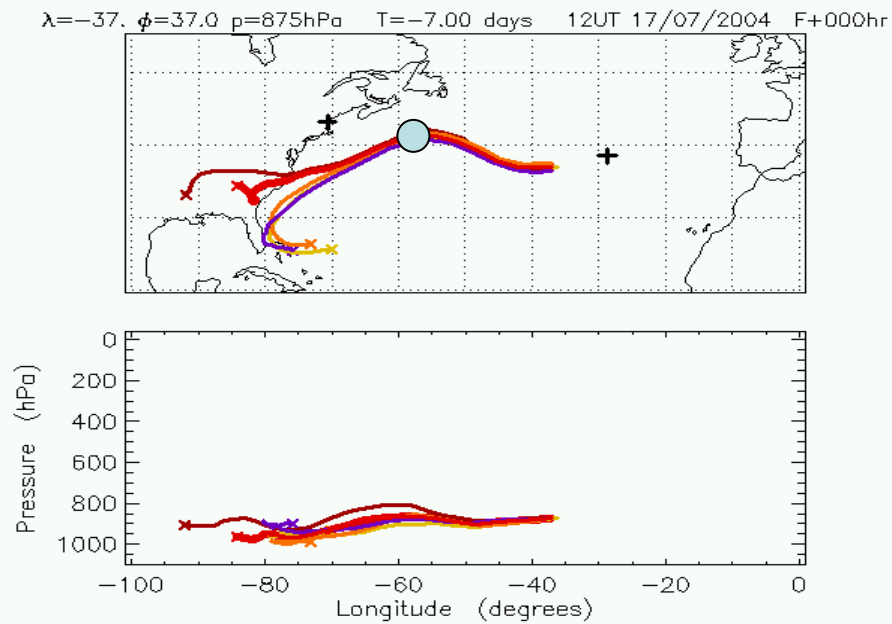


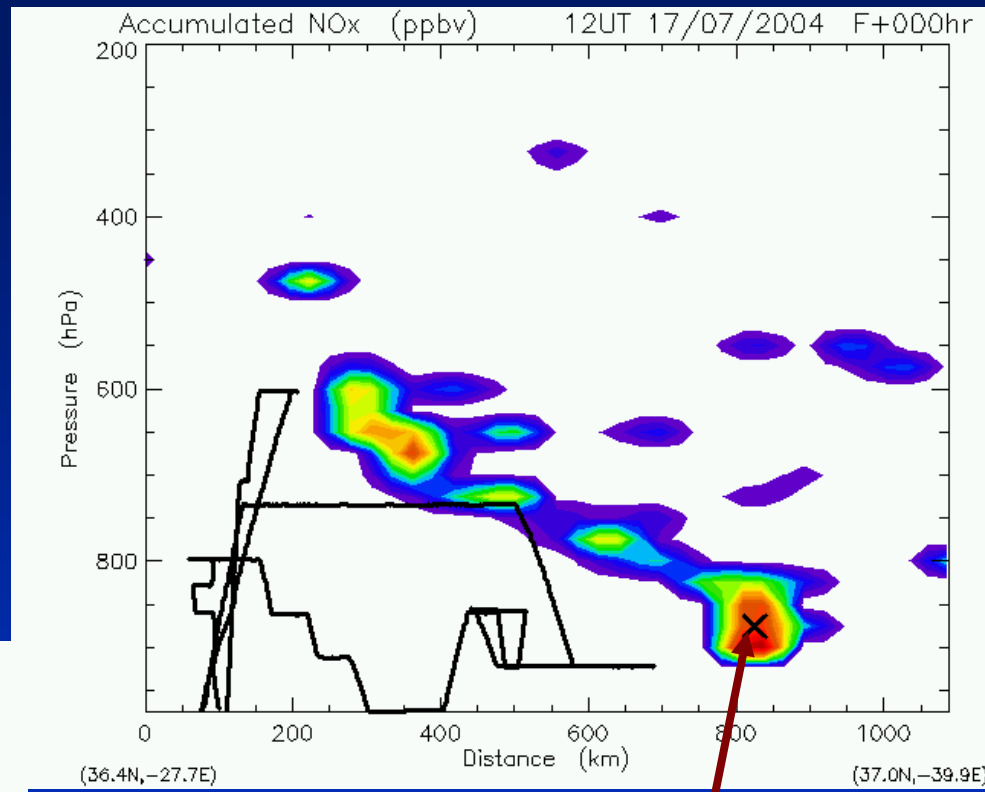
Horta

Air passing close to Pease

B030: 17/07/04 First Lagrangian opportunity





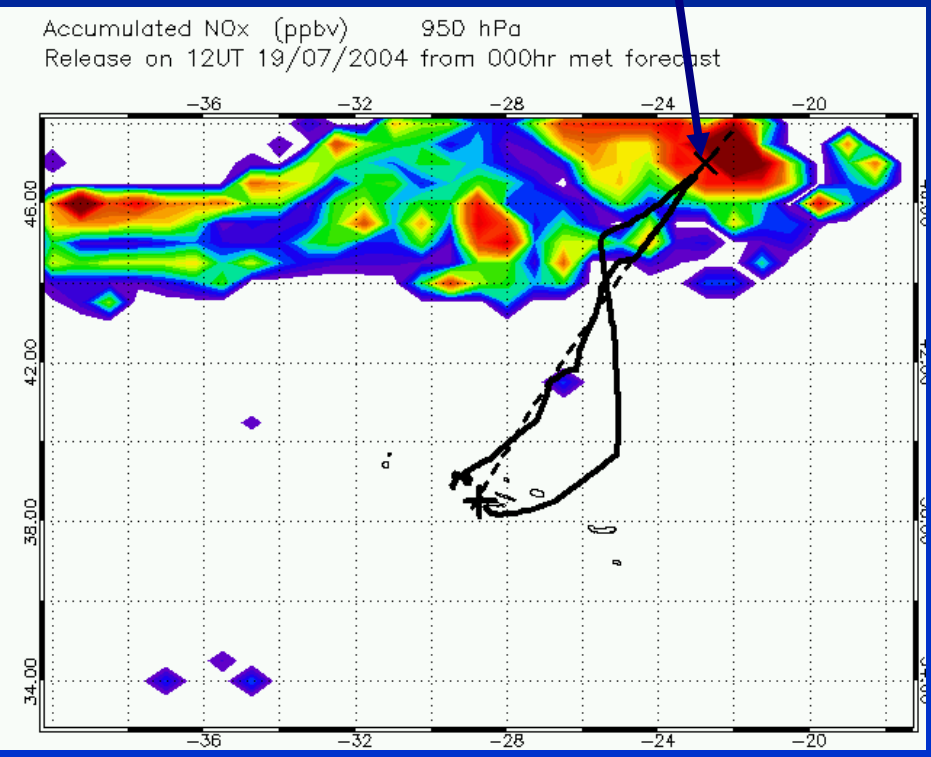


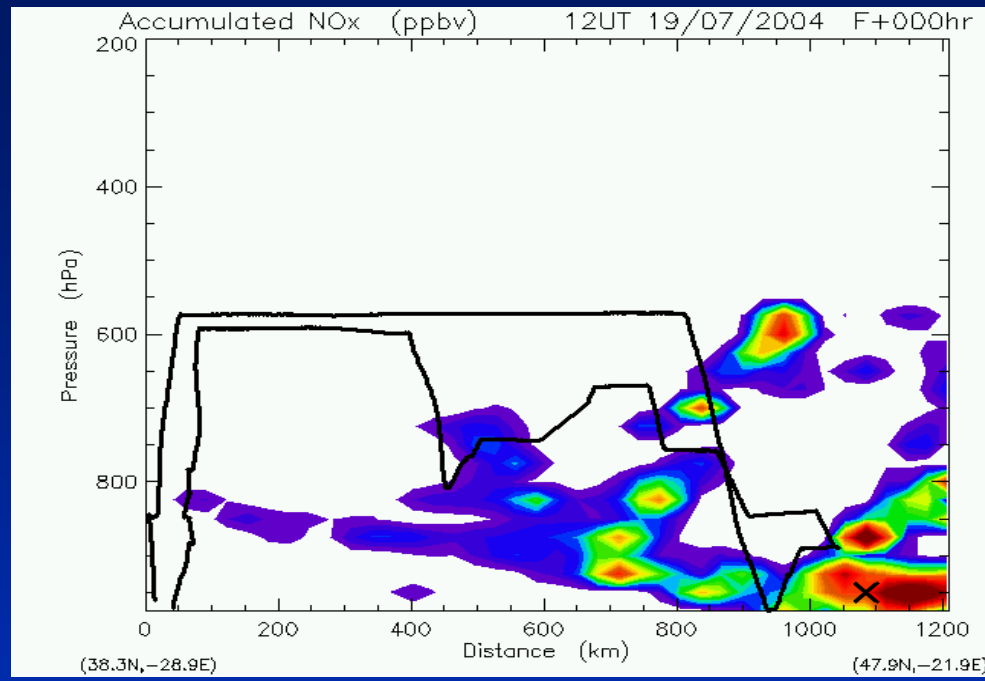
Target sampled by P3 on 15 July

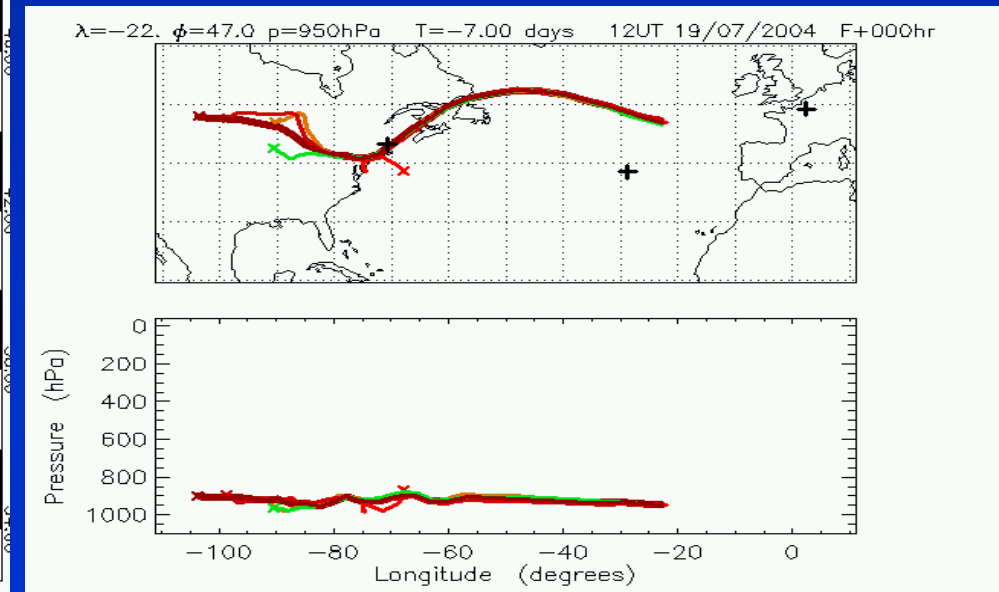
Unfortunately only skimmed edge because out of time.

B031: 19/07/04 “New York plume”

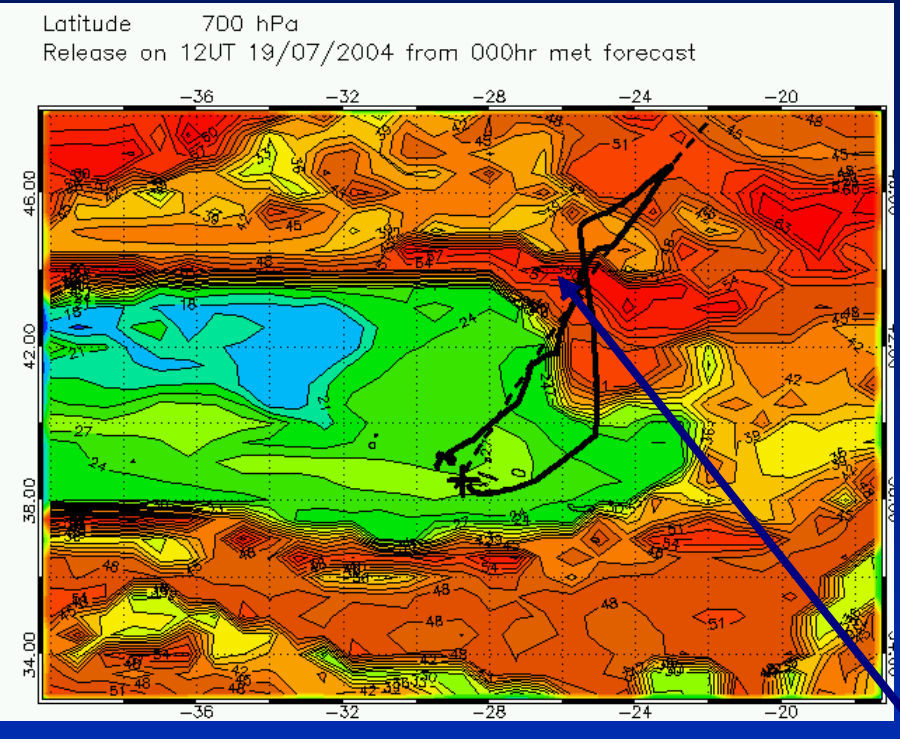
Target sampled by P3 on 15 July (on limit of range)

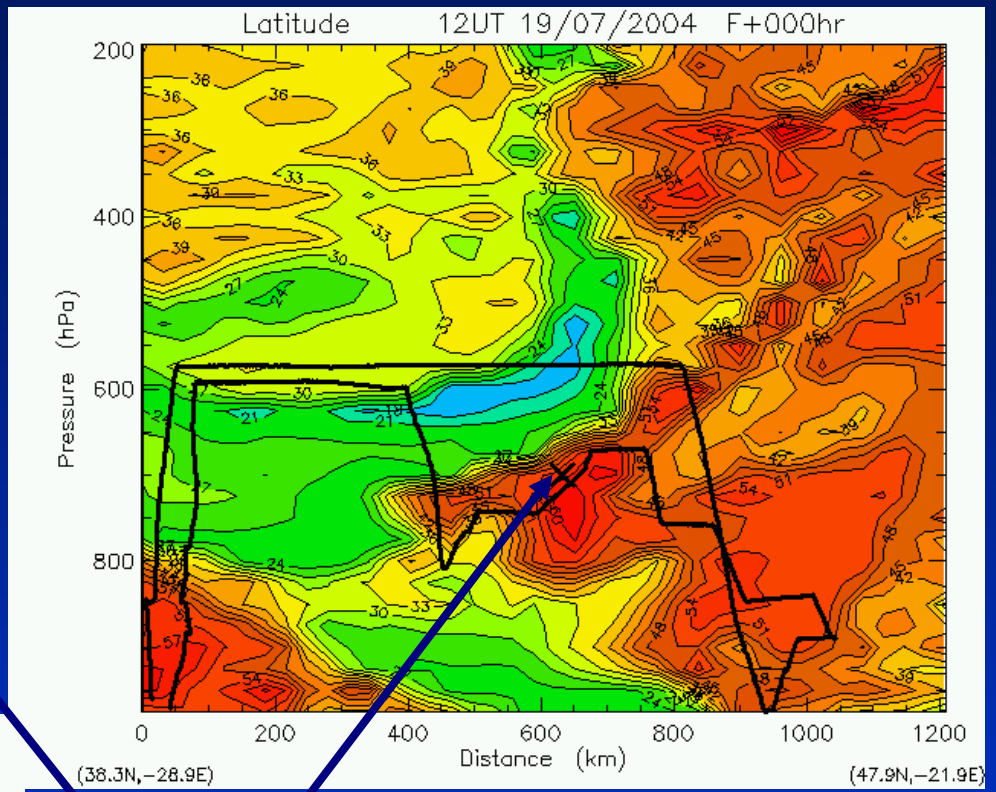


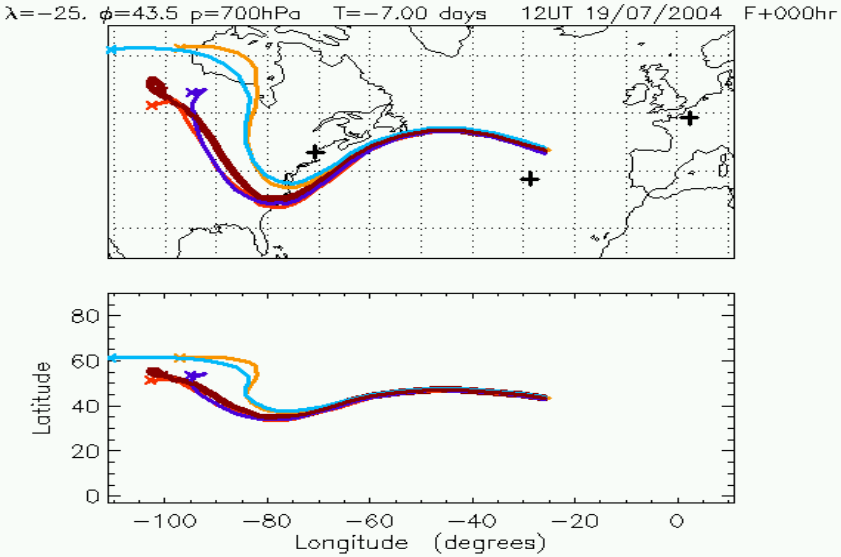




B031 continued: thin brown fire layer



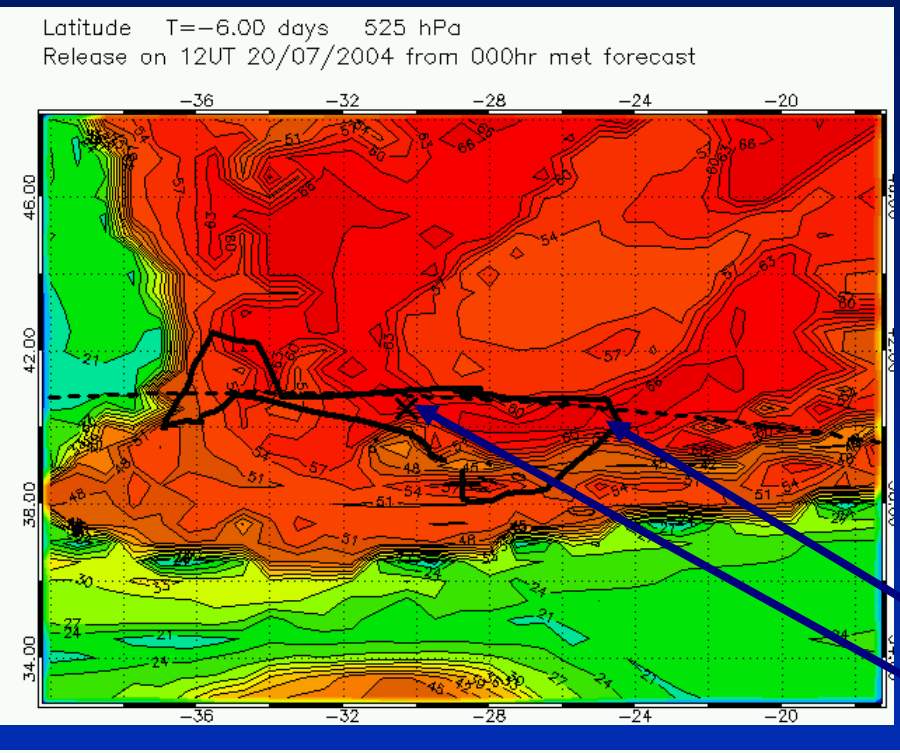


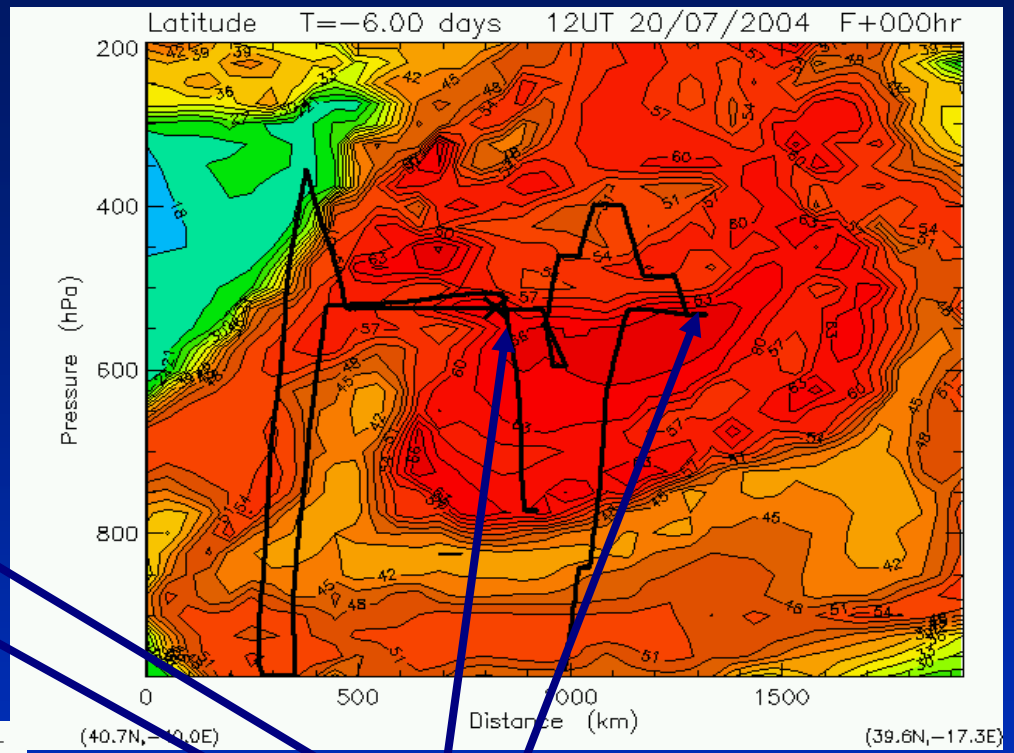


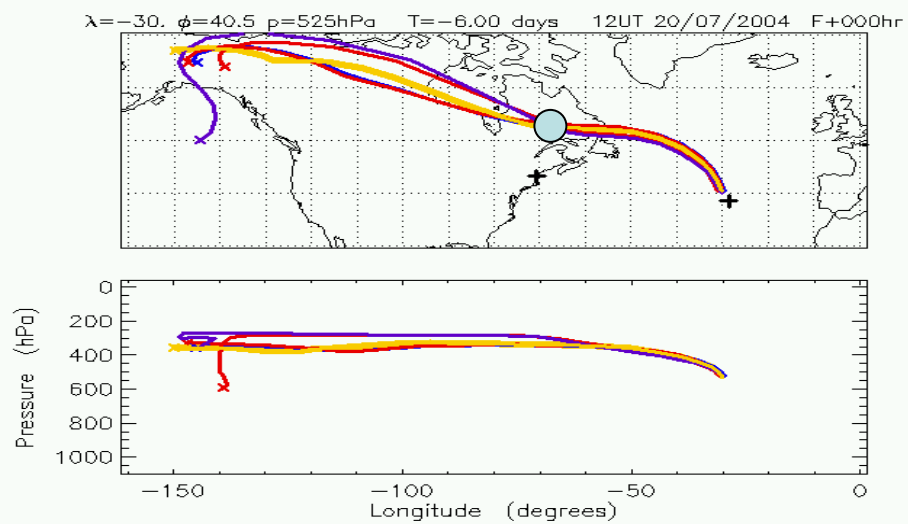
Narrow filament and thin layer - visibly brown. Adjusted altitude to stay within layer.

Originated from UT above Alaskan forest fires (but diluted by mixing while thinning).

B032: 20/07/04 Alaskan forest fires

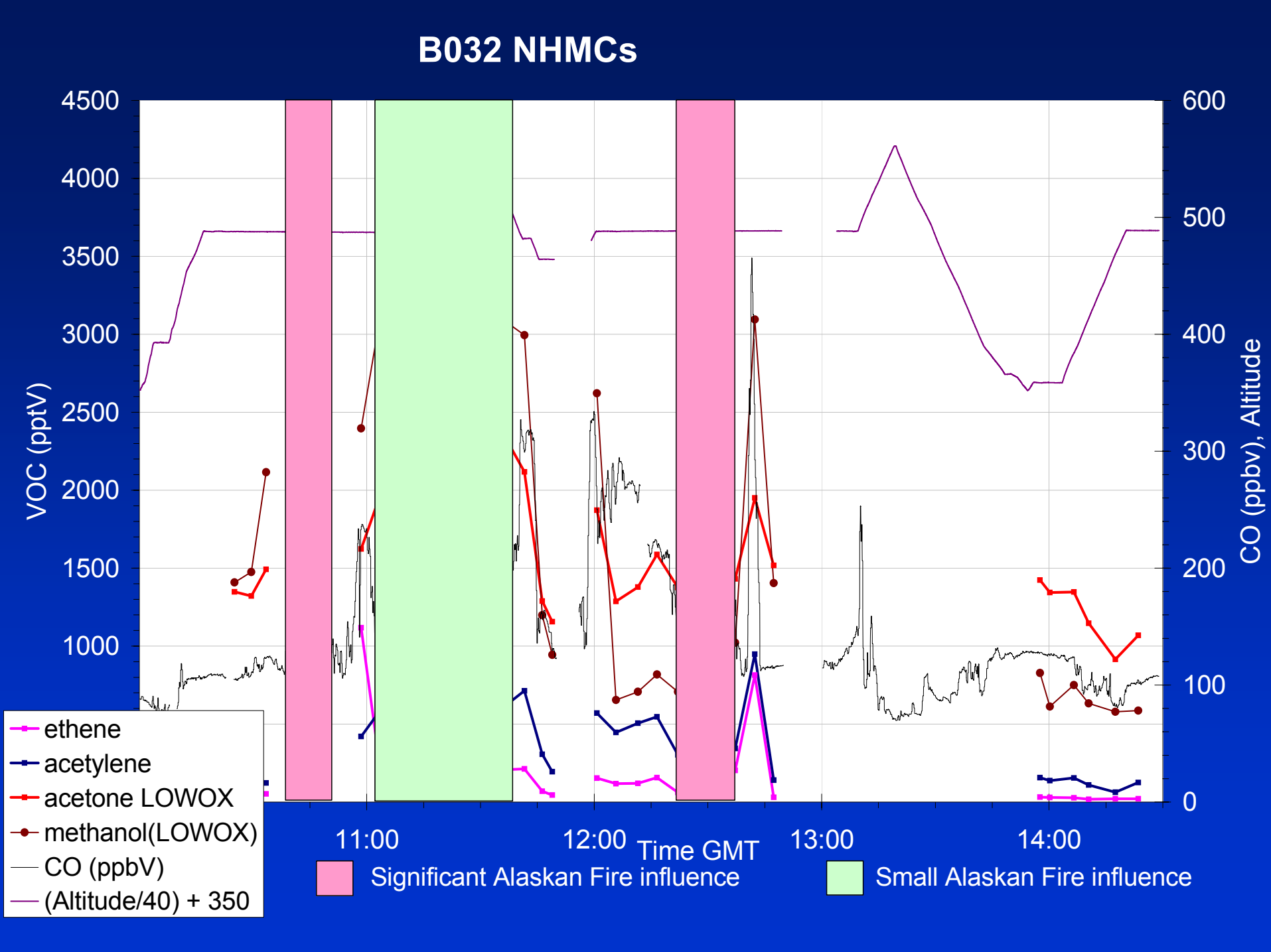




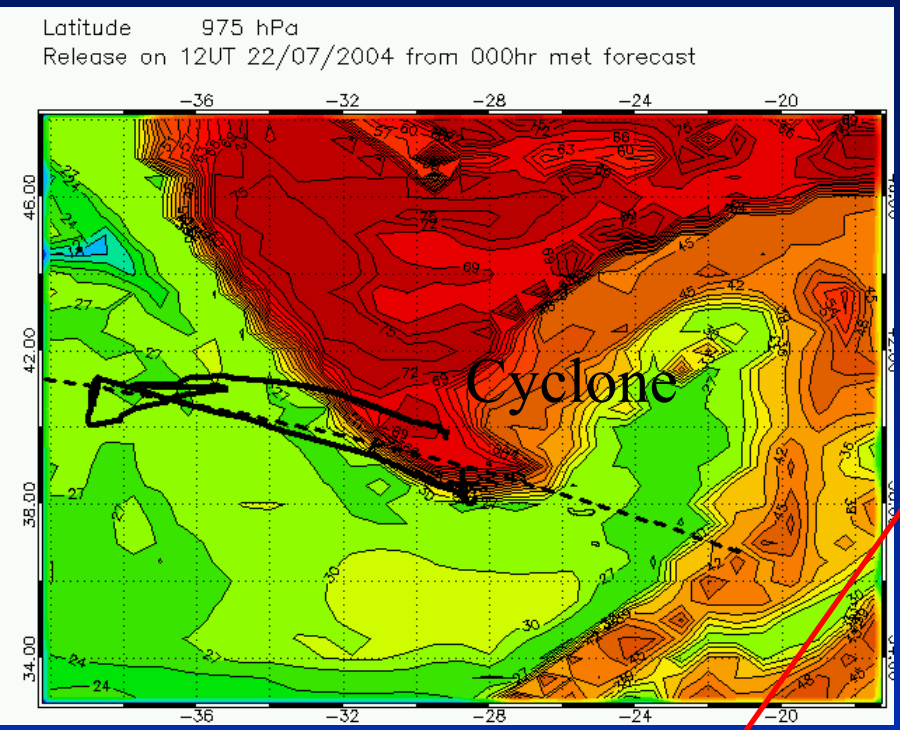


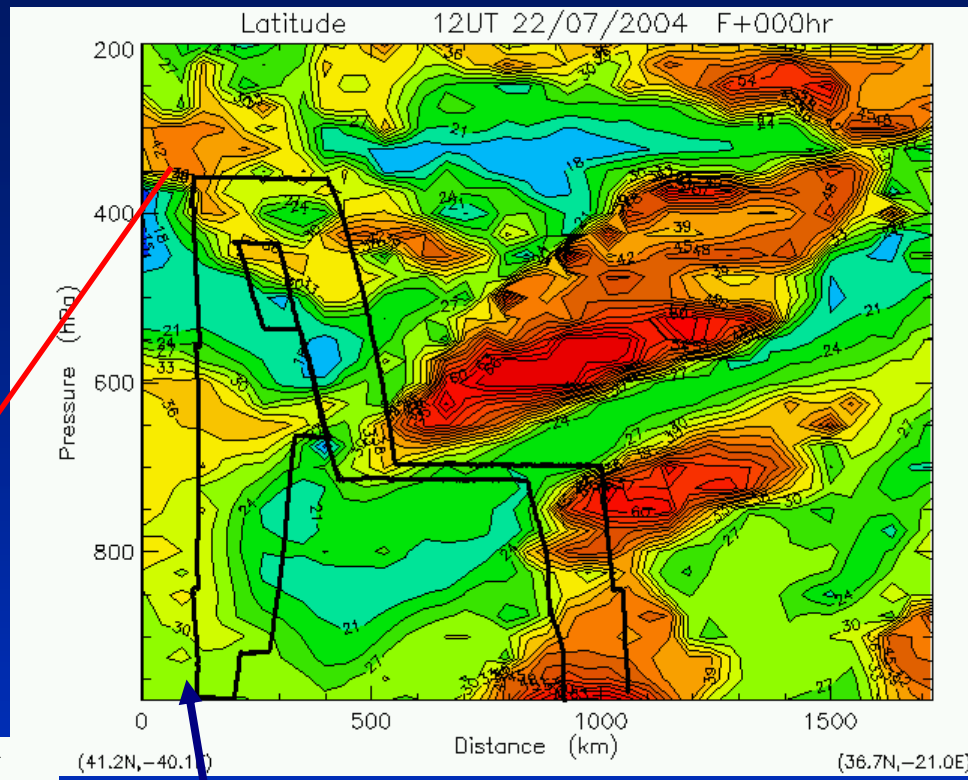
Alaskan fire plume with CO up to 600ppb. Similar plume was intercepted by P3 on 15 July (but not same air mass).

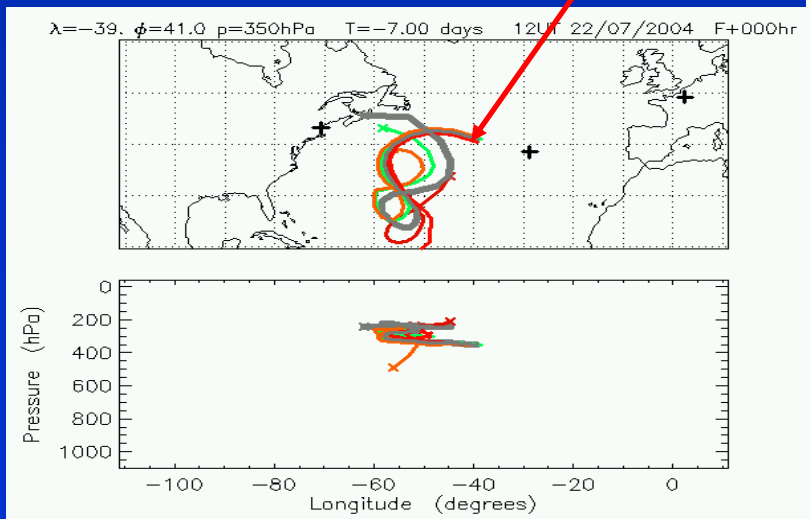
Was targeted on 23/7 by Falcon.


B032 NHMCs
4500
4000
3500
3000
2500
2000
1500
1000
VOC (pptV)
600
500
400
300
200
100
0
CO (ppbv), Altitude
11:00
12:00
13:00
14:00
Time GMT
ethene
acetylene
acetone LOWOX
methanol(LOWOX)
CO (ppbV)
(Altitude/40) + 350
Significant Alaskan Fire influence
Small Alaskan Fire influence

B033: 22/07/04 ENVISAT underpass

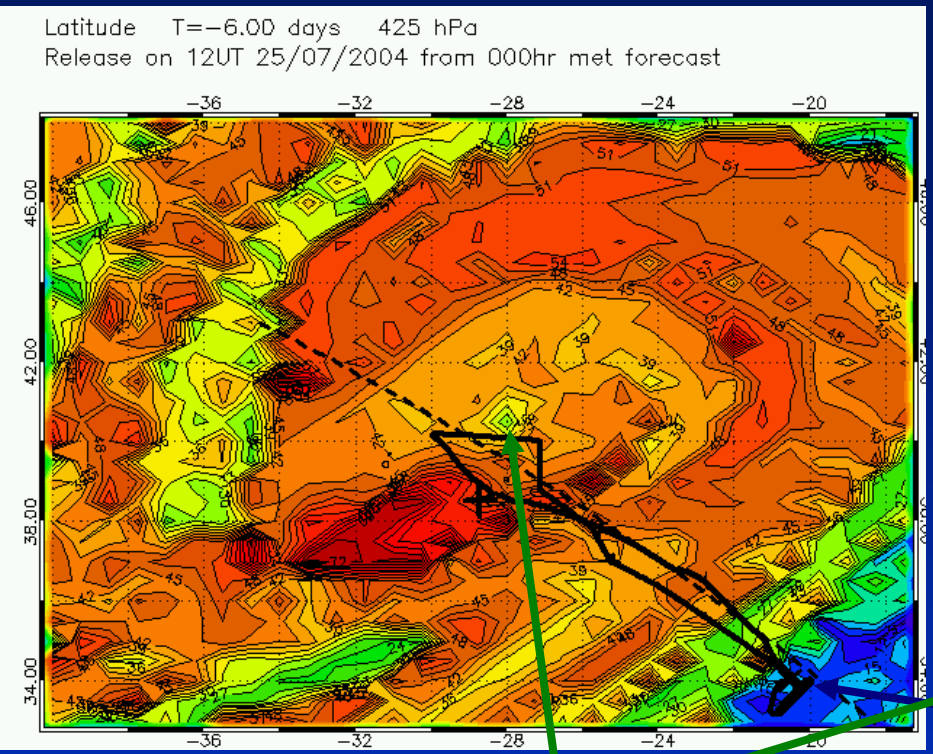


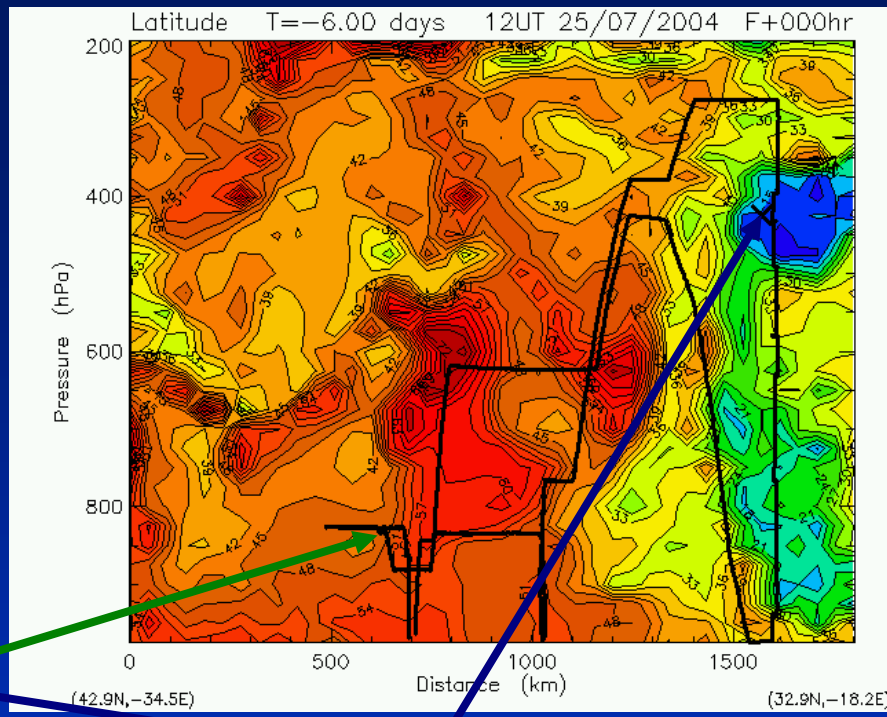




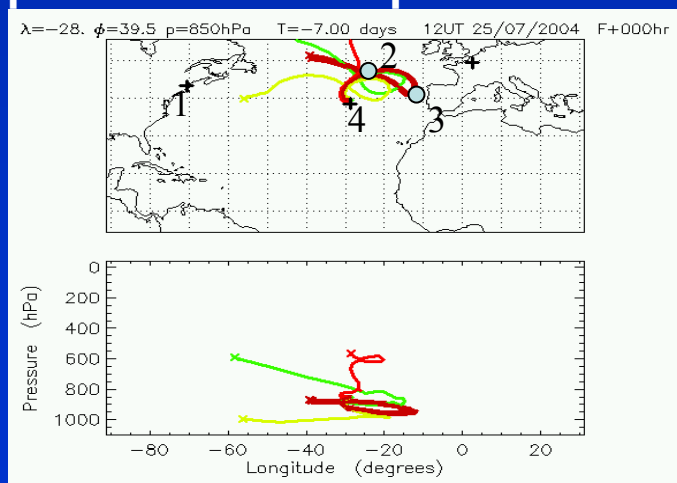
Deep profile under satellite through air re-circulating over mid-Atlantic for more than a week.

B034: 25/07/04 African air

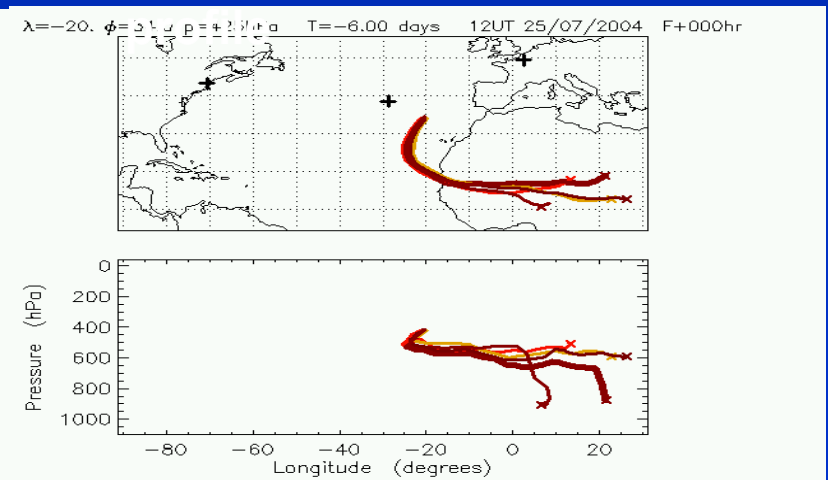




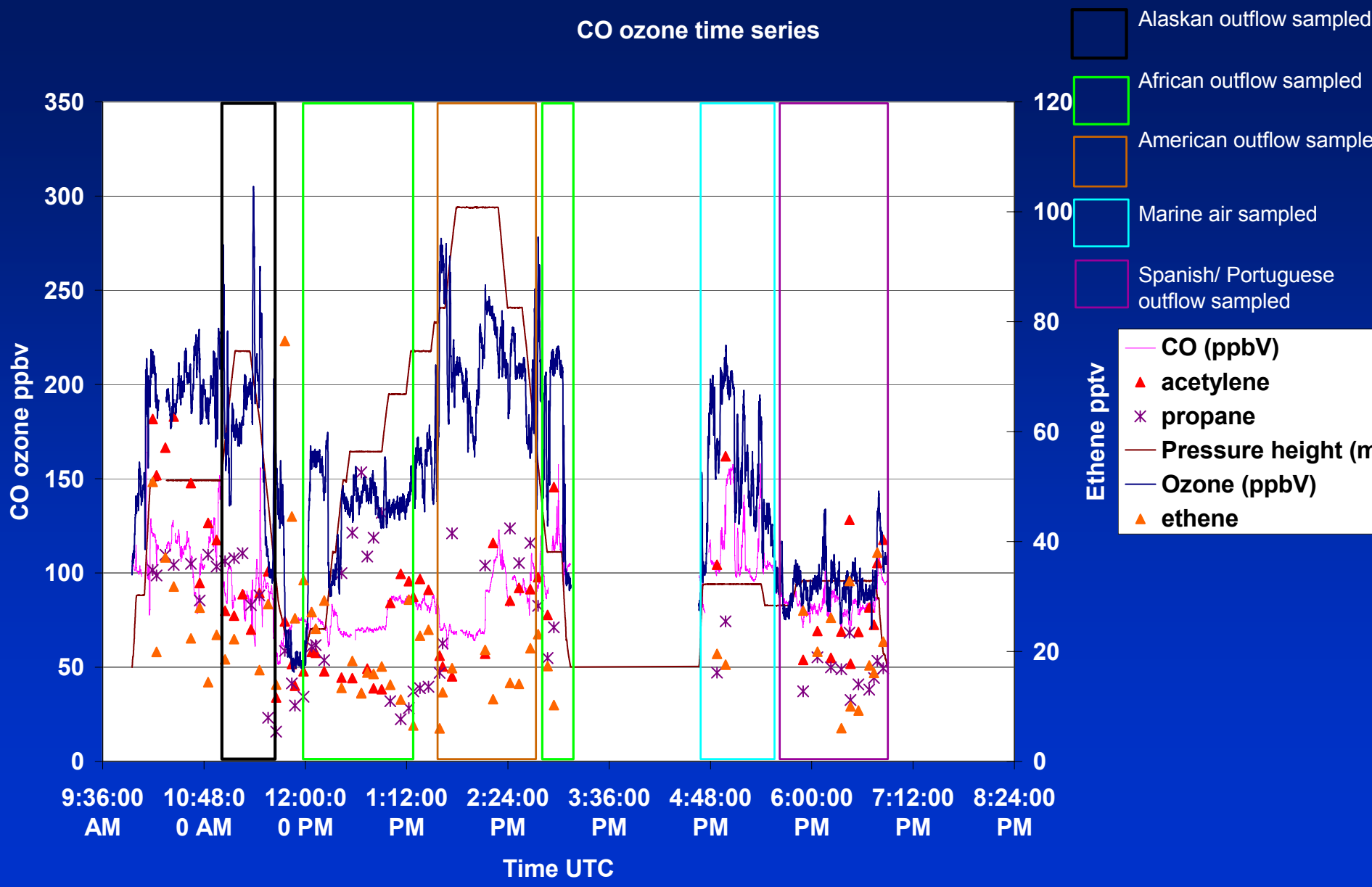
New York plume 4th interception



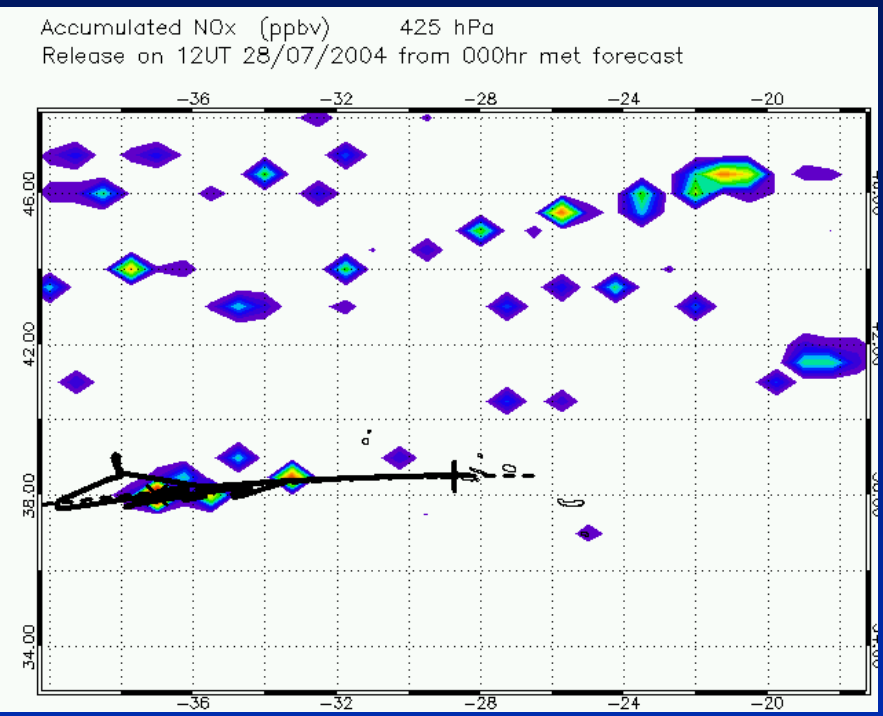
African air throughout

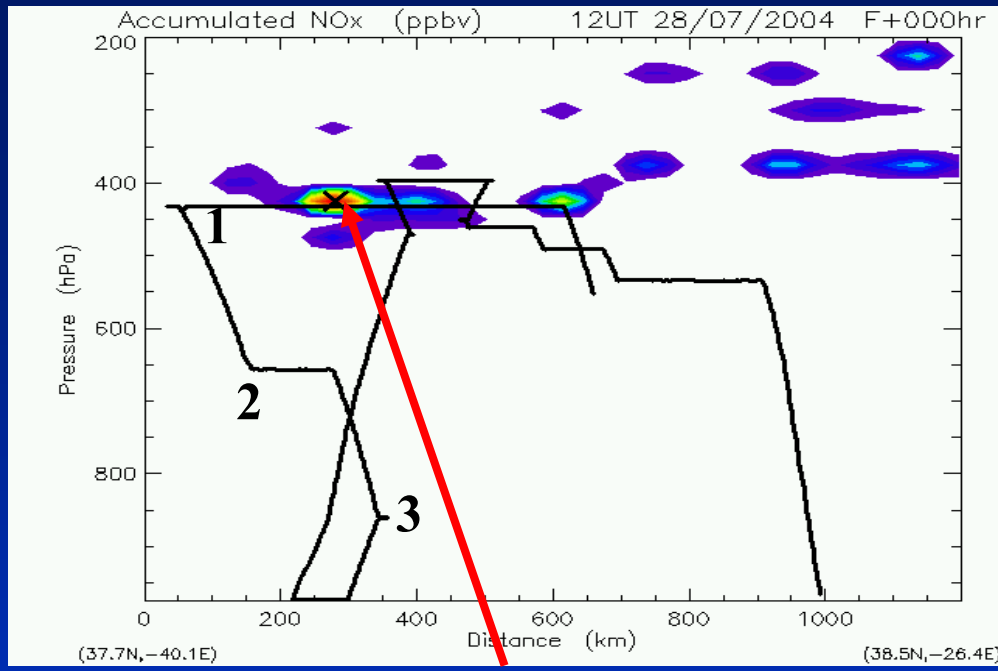


B034: 25/07/04 African air

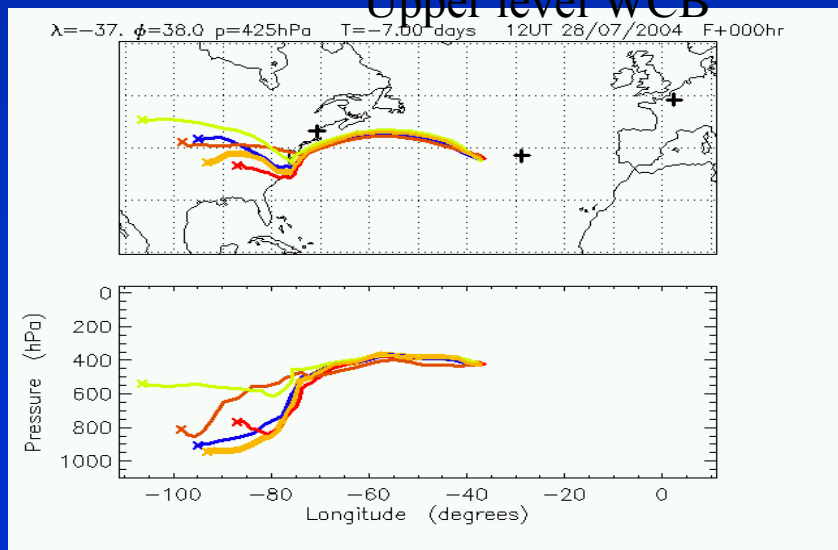


B035: 28/07/04 Comparison with DC8



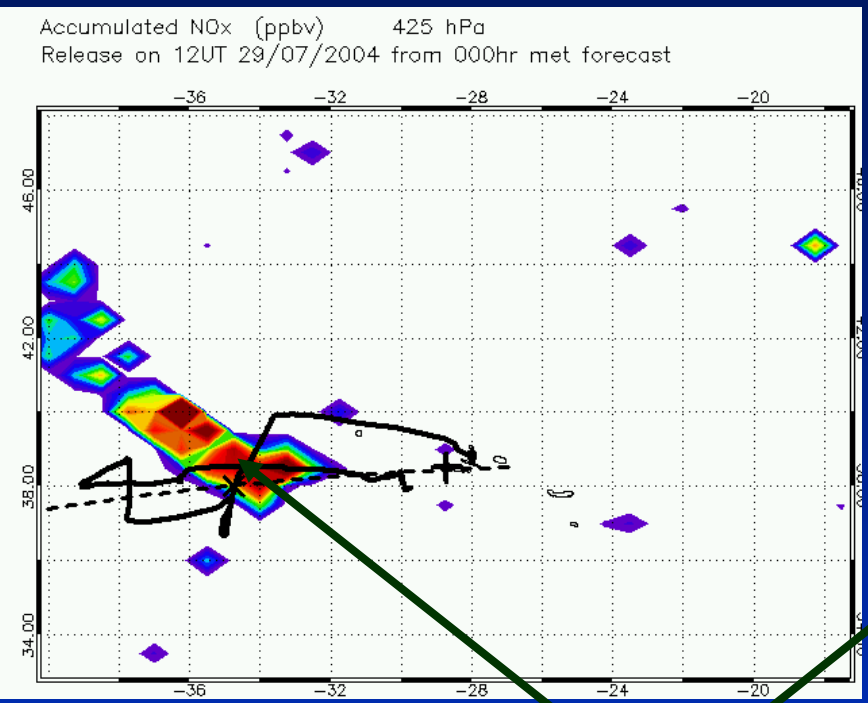


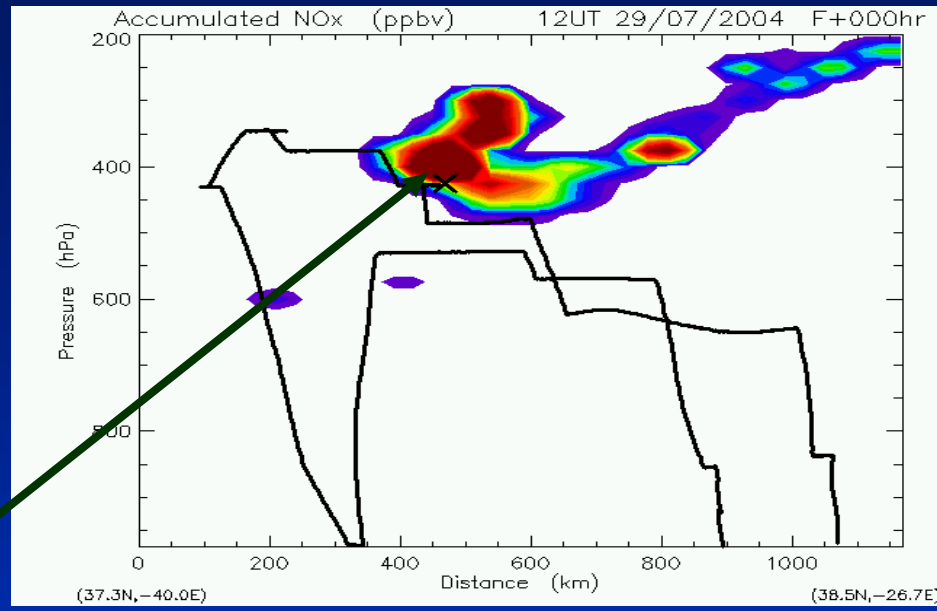
Upper level WCB



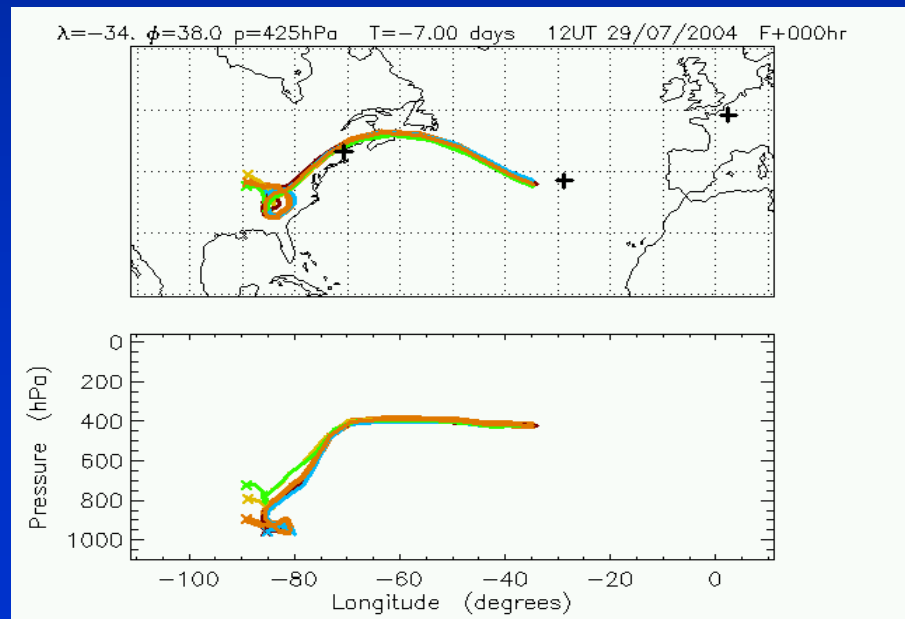
Comparison below air exported by WCB. Relatively clean but sampled again by Falcon on 30/7 and 31/7.

B036: 29/07/04 Upper level export in WCB

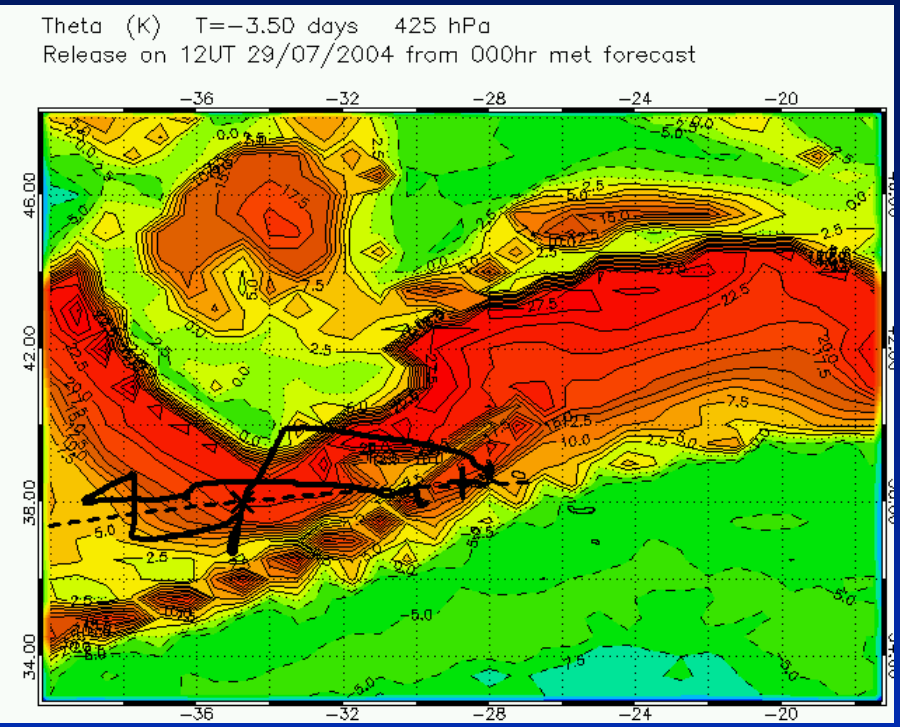


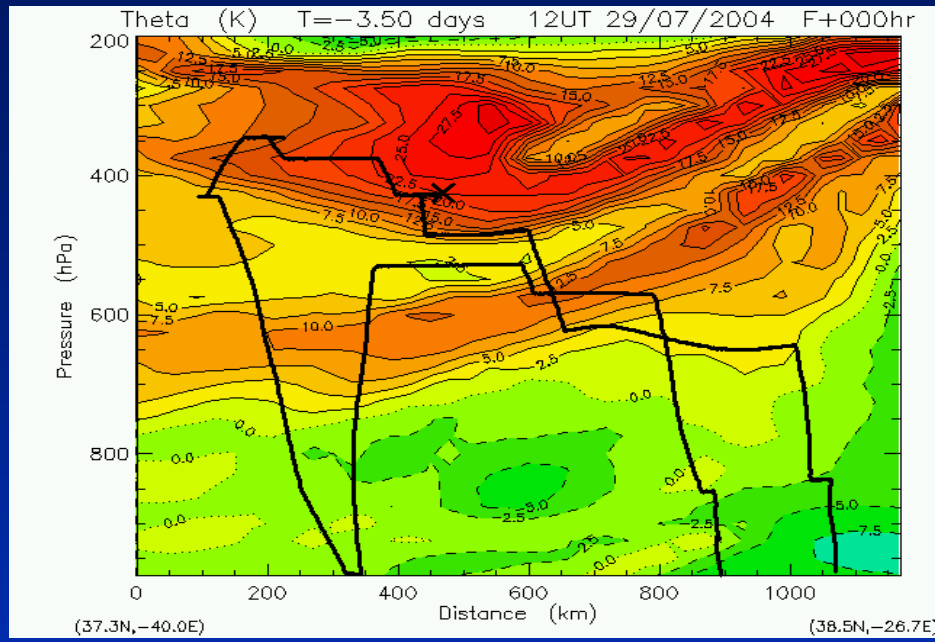


Polluted air on North side of WCB but crossed under maximum because could not achieve altitude early enough.



B036 continued: WCB features

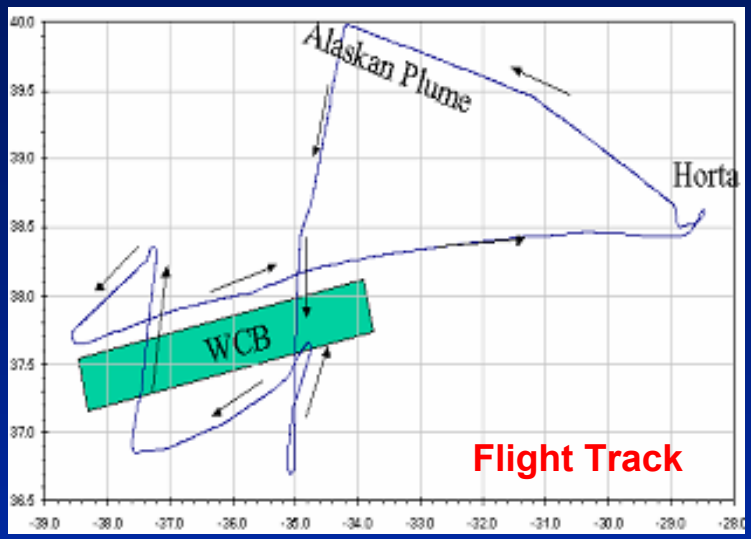


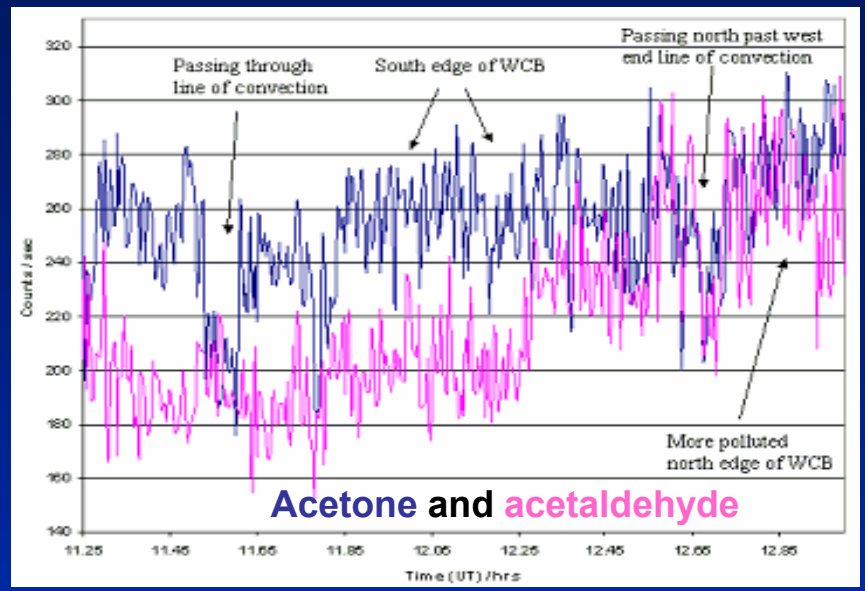


Observed line of convection (dashed line) was parallel to feature lying to south at upper levels (figure above)

Narrow line of deep convection – BA146 flew along south side and then a deep profile on north side

Flight B036

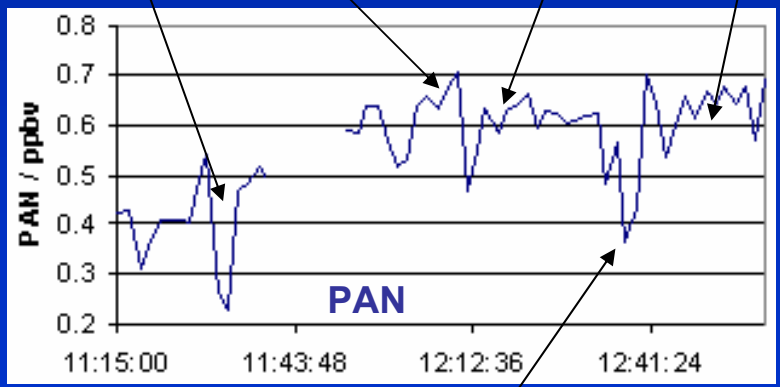




Through Cu-Nim gap

Along northern edge of WCB

Along southern edge of WCB

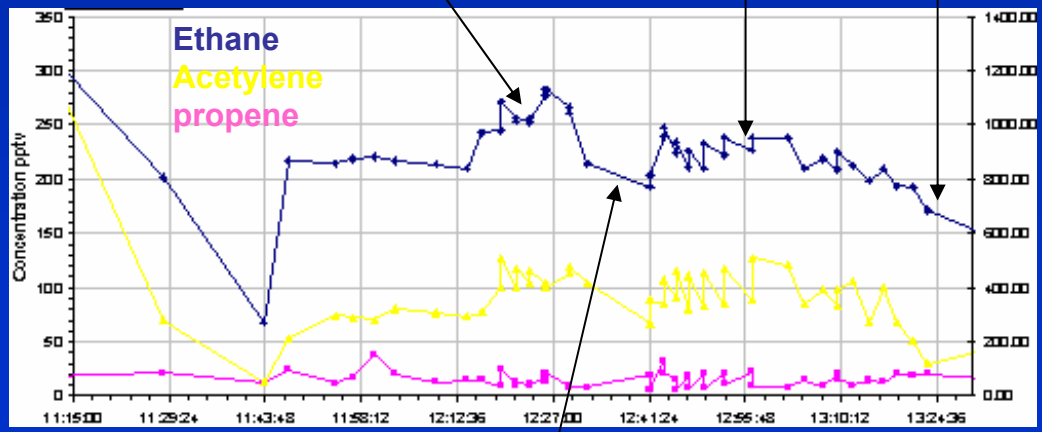


Passing north through western end of line of convection

Bottom of WCB outflow at FL180-160.

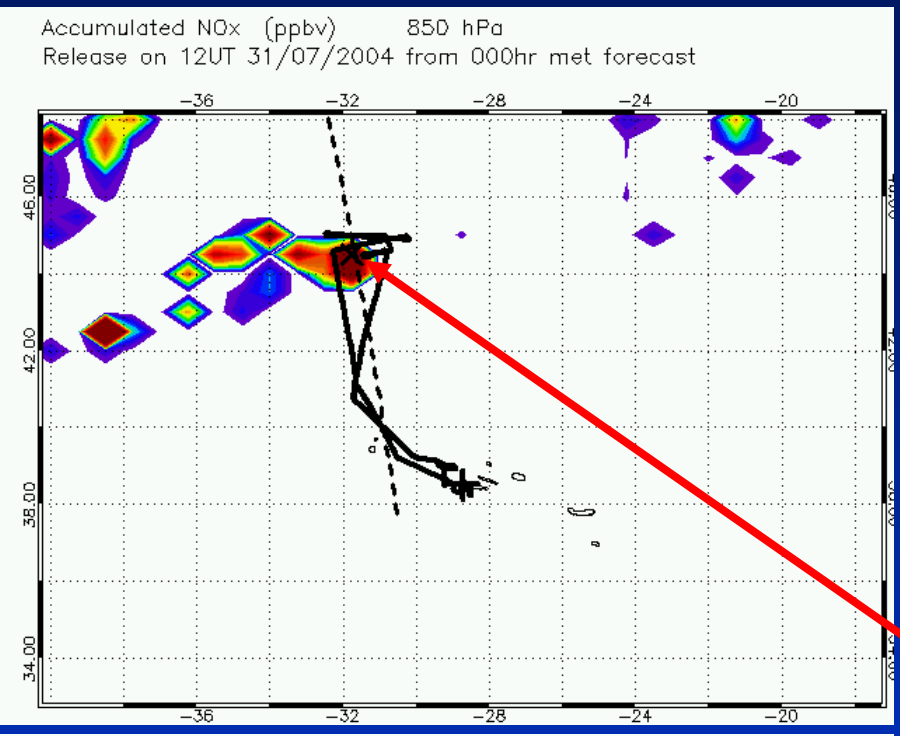
Southern edge of WCB

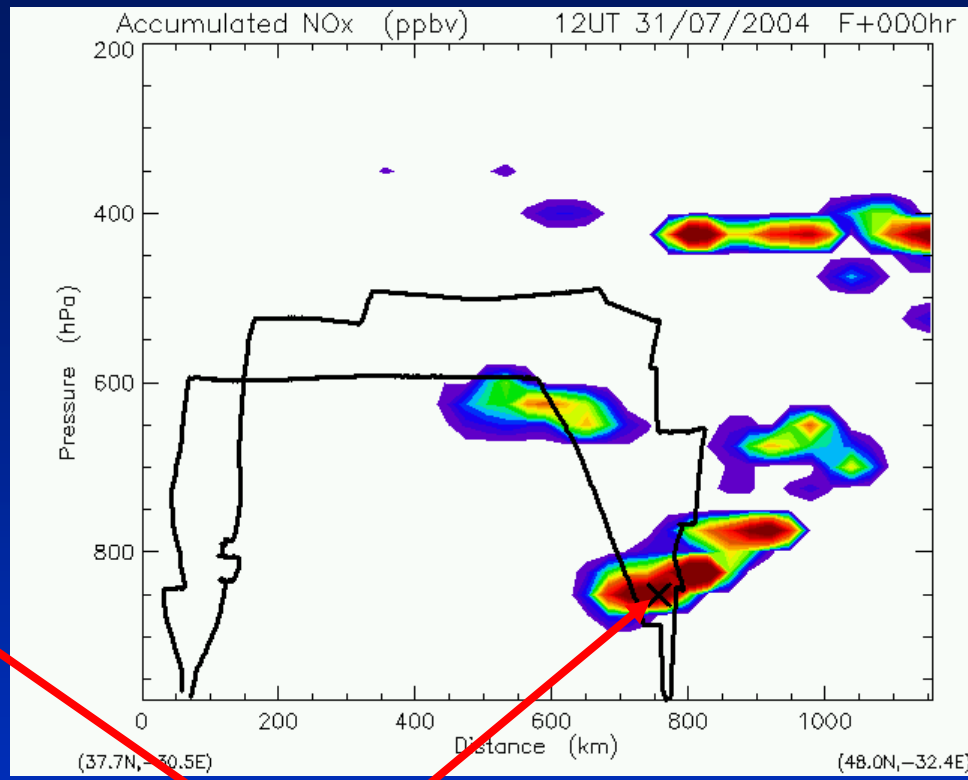
North of WCB

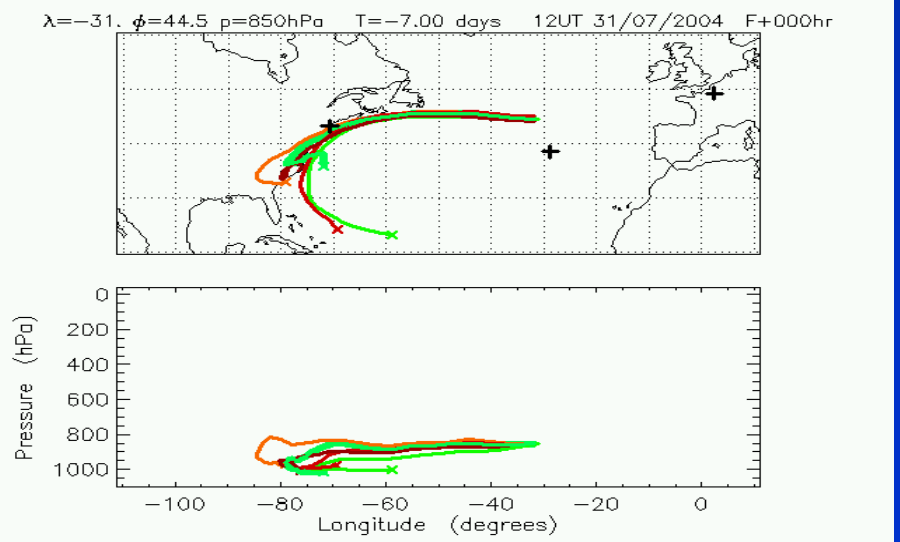


Crossing line of convection at western edge

B037: 31/07/04 Low level WCB (1)

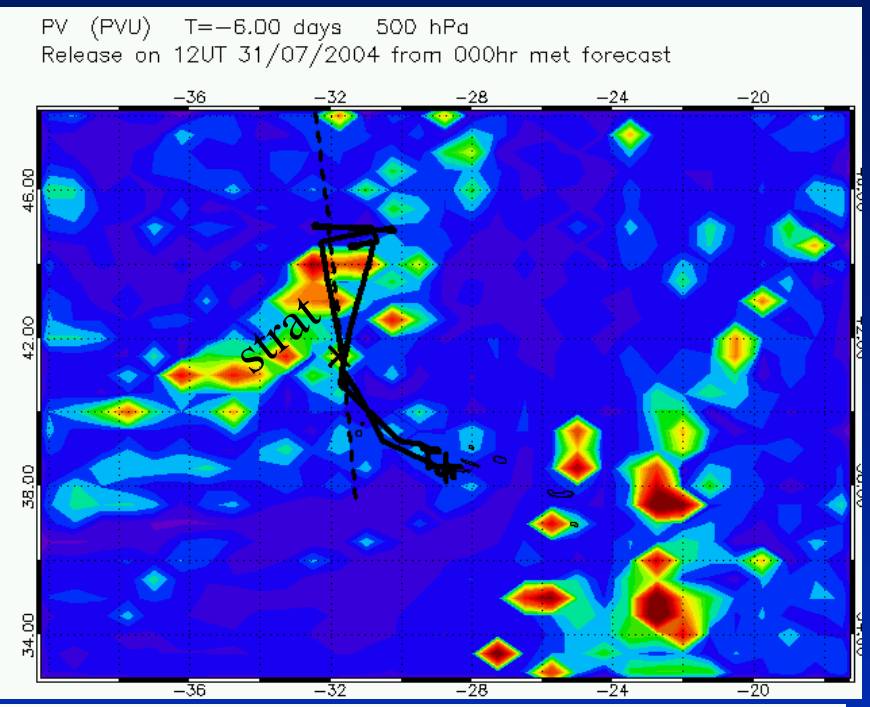


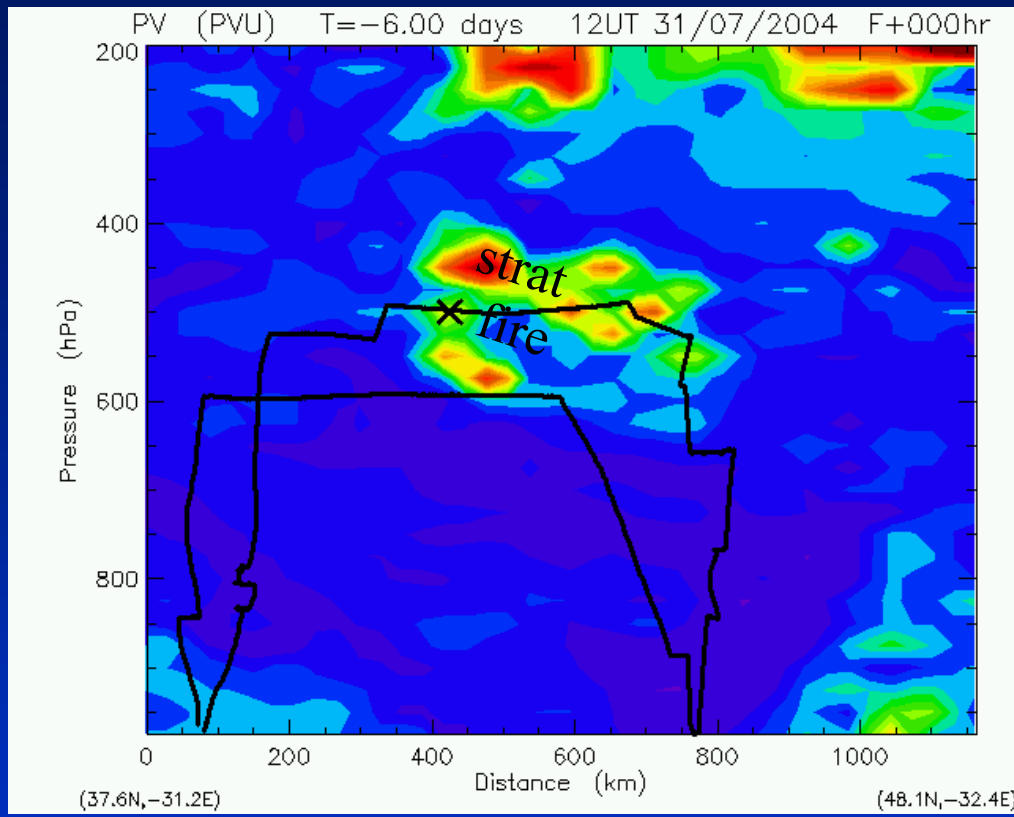


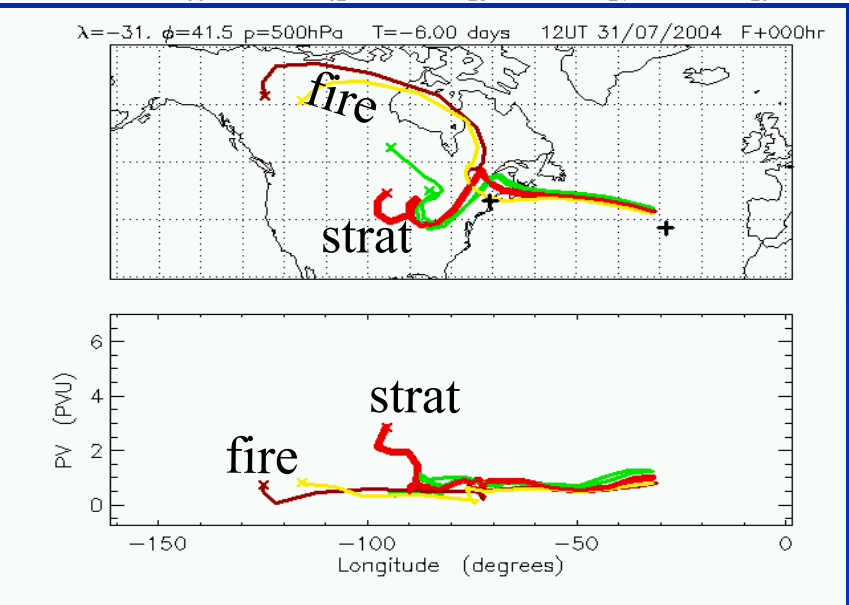


Target already sampled by P3 on 27 and 28 July

B037 continued: forest fire mixed with stratospheric air

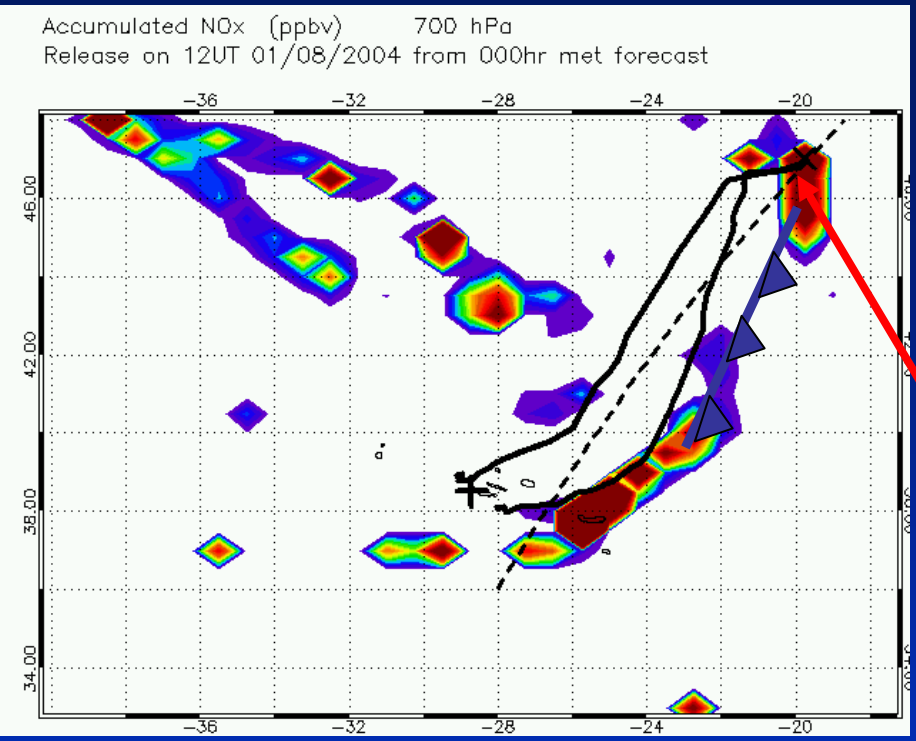


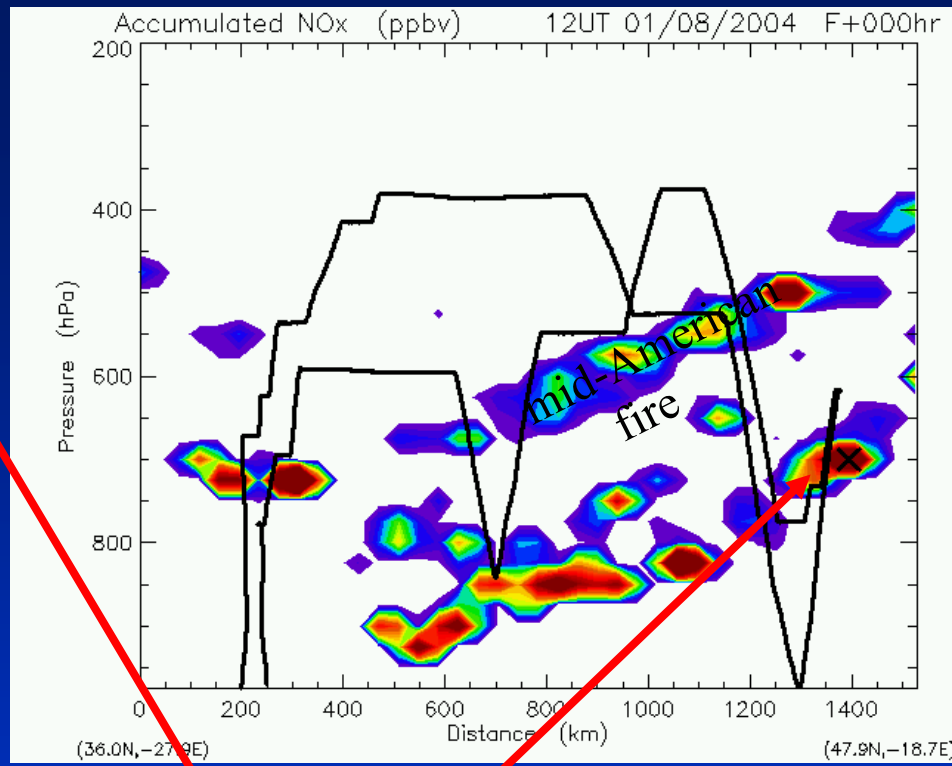


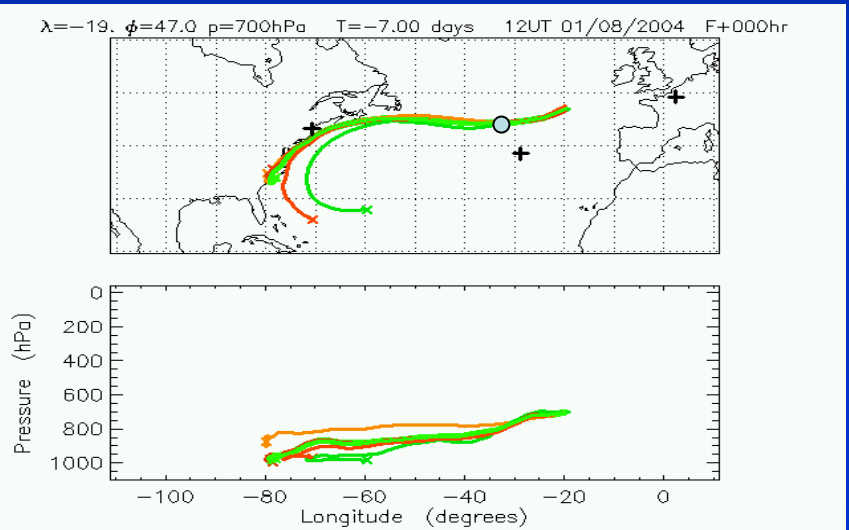


Strong evidence for forest fire CO mixed with stratospheric ozone

B038: 01/08/04 Low level WCB (2)

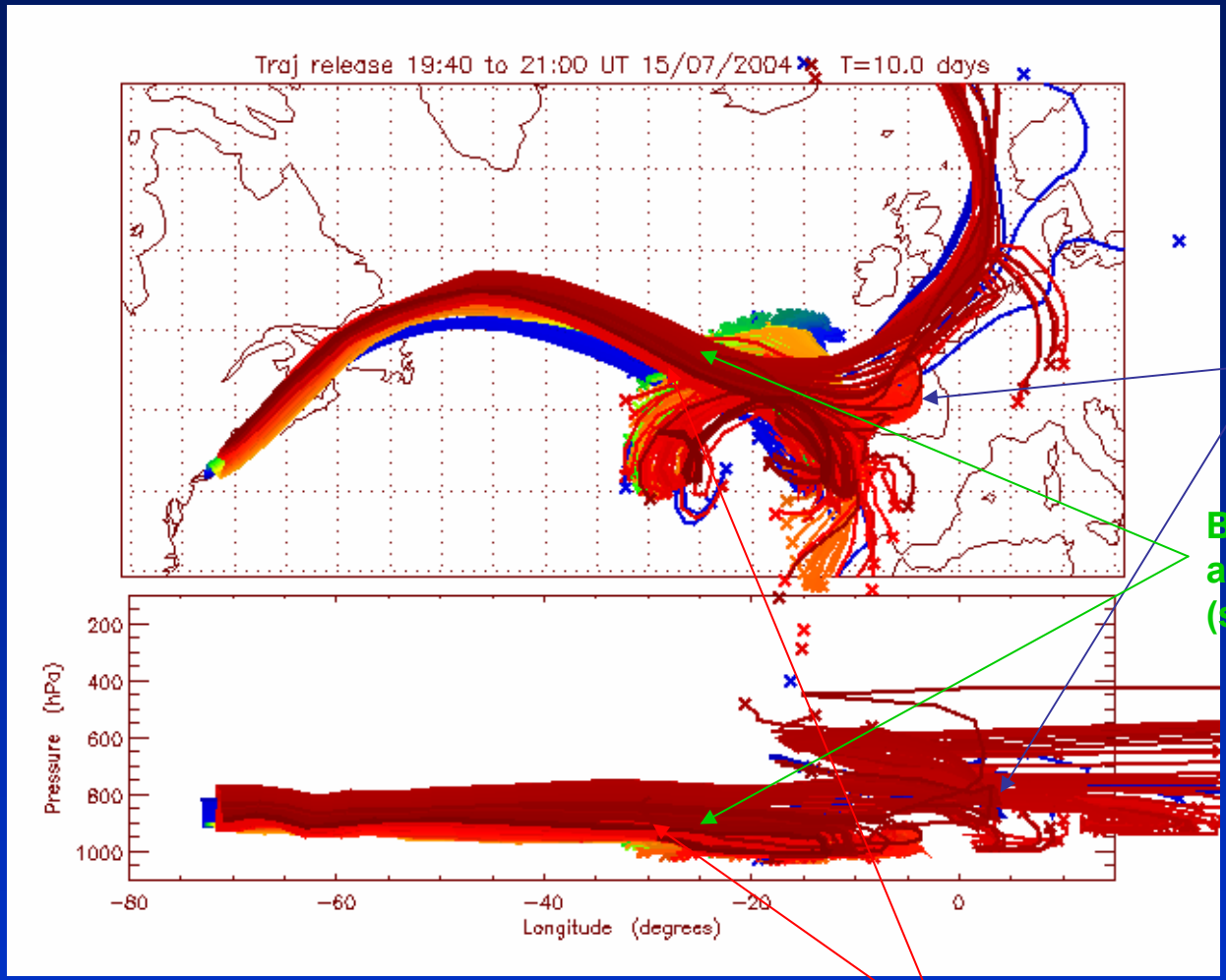






Rapidly receding target already sampled by P3 on 27 and 28 July and BAe146 on 31 July.

Possible multiple interception of New York polluted airmass: 1



Intercepted by DLR Falcon off NW corner of Spain on 22/7 (saw CO ~ 90-100ppb).

BAE146 flight intercepted this air again on 25/7 (saw increased CO ~ 115-125ppb).

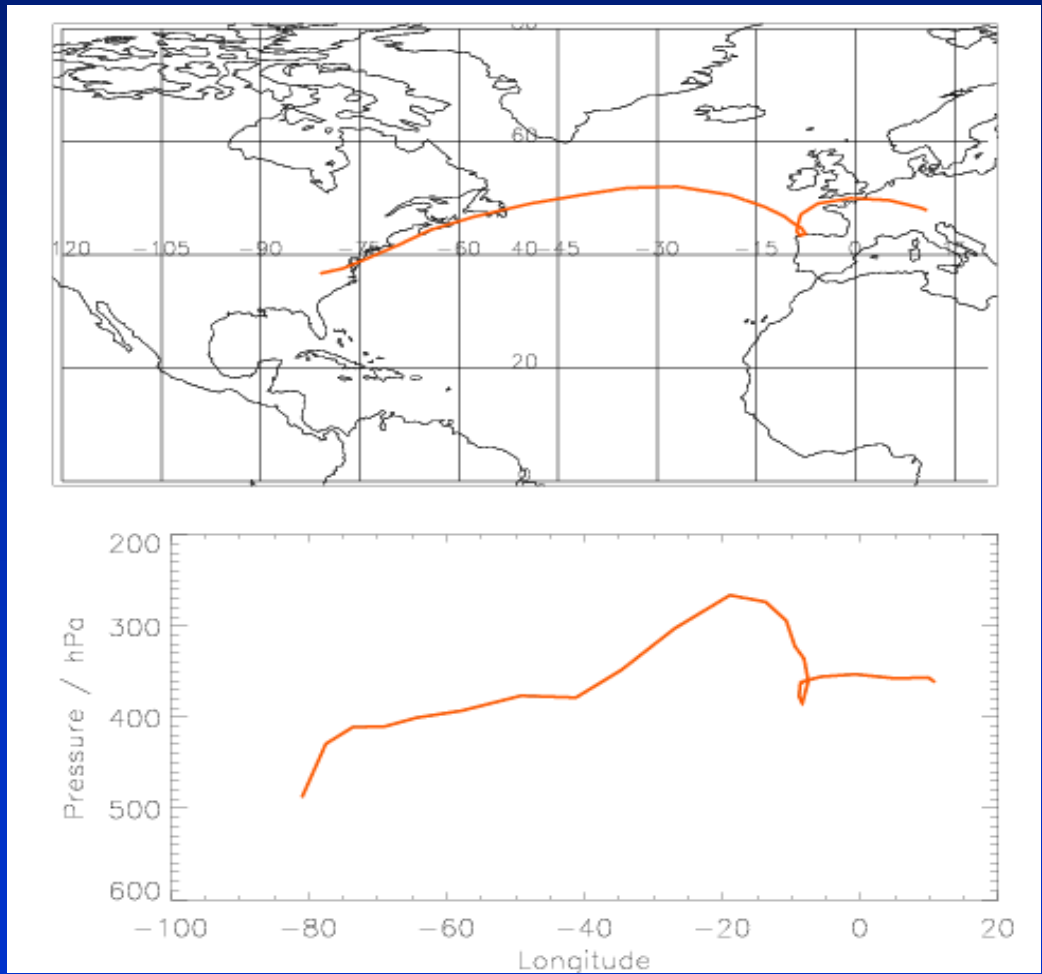
10 day forward trajectories from NOAA P3 flight off NYC on **15/7**. Airmass doubles back from Spain to the Azores.

BAE146 flight intercepted this air on 19/7 (saw CO ~ 115-125ppb).

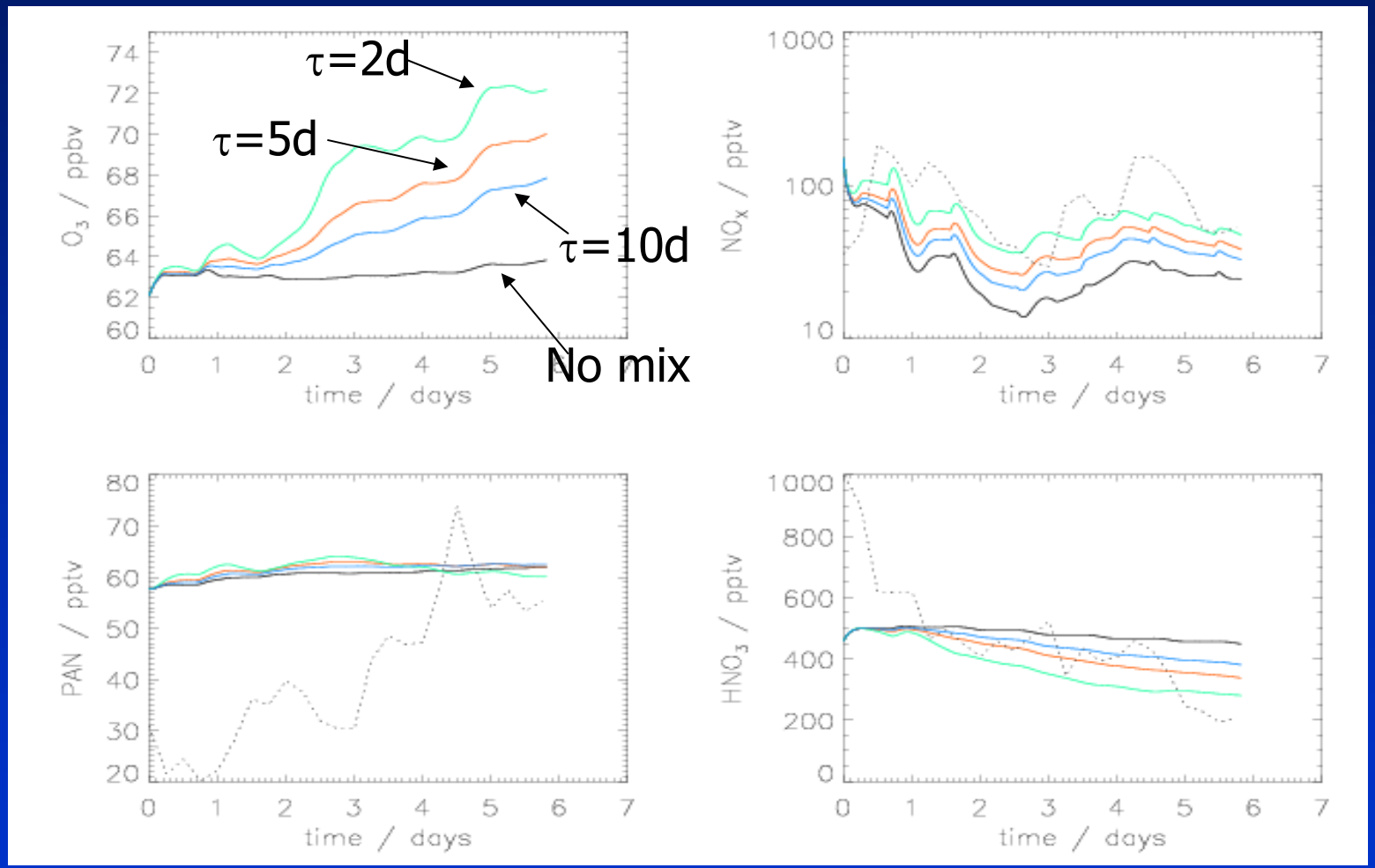
Sensitivity Analysis

Use Lagrangian model to investigate sensitivity of trans-Atlantic ΔO_3 to:

- Mixing rate
- Cloud cover
- ECMWF water vapour
- NMHC complexity
- Initial conditions

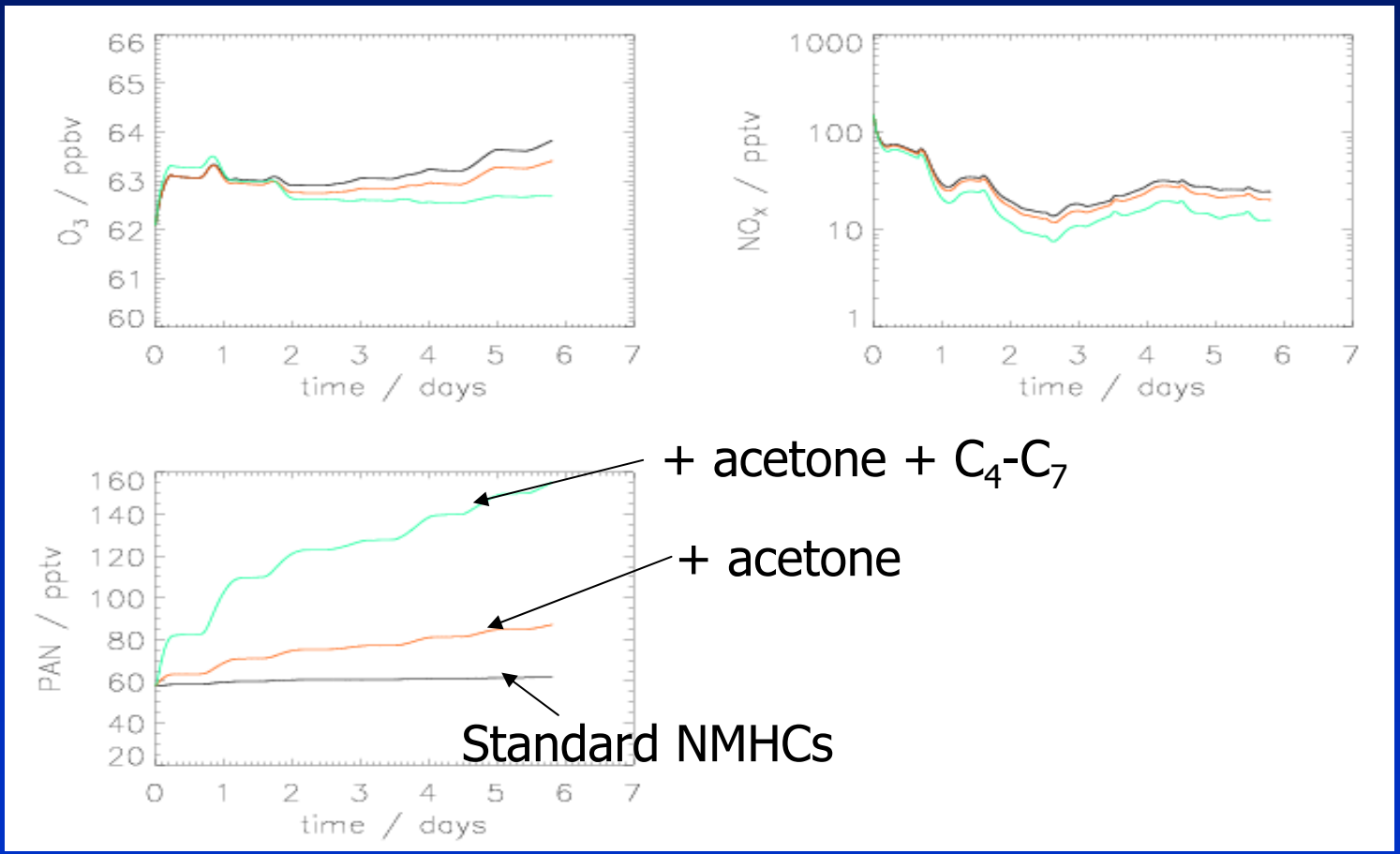


Mixing Rate



More NOx mixed into air mass ⇒ *more ozone produced*

NMHC complexity



Formation of PAN through NMHC oxidation

⇒ *less NOx available for ozone production*

Conclusions

- Trajectory forecasts are sufficiently accurate to execute intercontinental Lagrangian experiment.

- Uncertainties in observed ΔO_3 and air-mass matches influence diagnosis of trans-Atlantic photochemical ΔO_3.

Investigations Underway

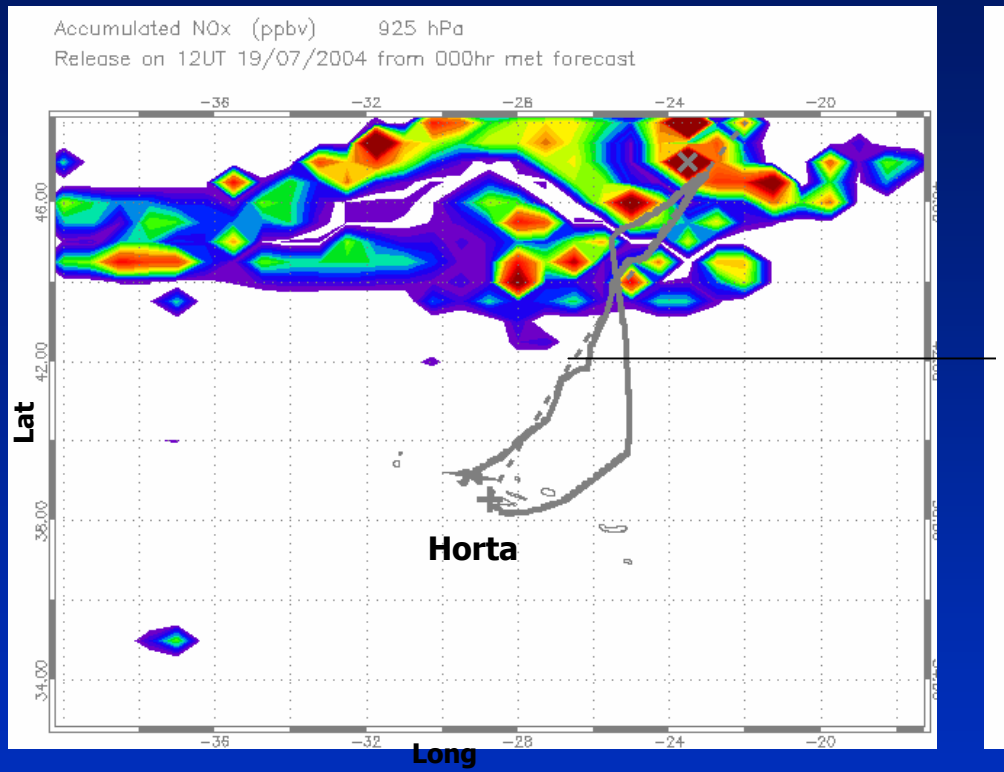
- Constraint of mixing term through hydrocarbons.

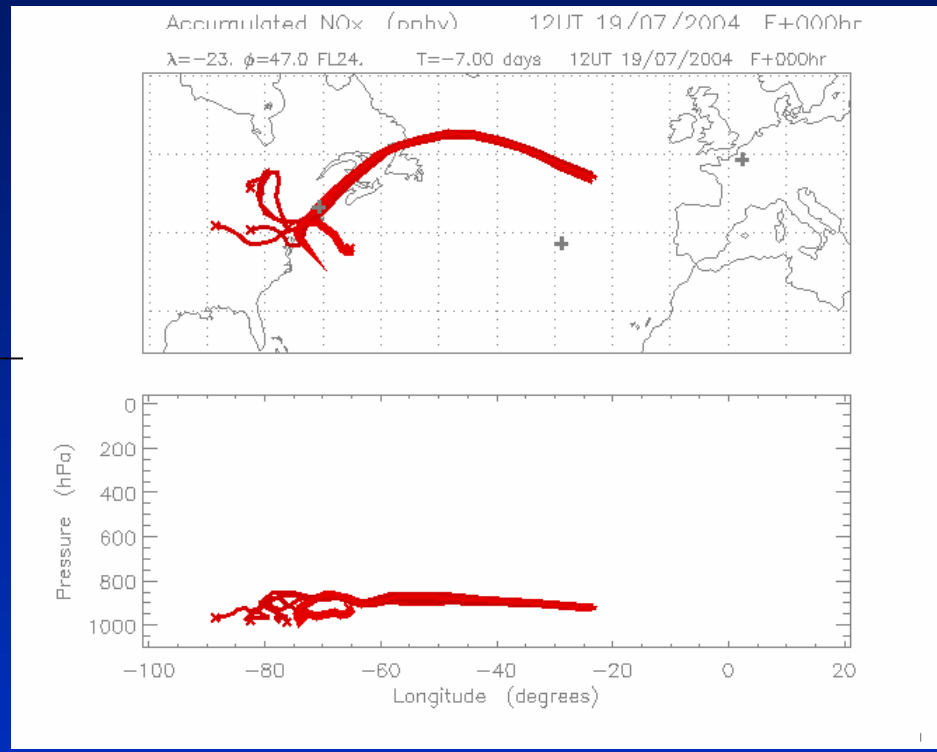
- Full Monte-Carlo analysis using Lagrangian model.

- Can reduced chemical mechanisms describe the observed change in composition or is complexity unavoidable?

Possible multiple interception of New York polluted airmass 2

First BAE146 interception flight into NYC air 19/7





- NOx emissions tracer on 925hPa on 19/7 with BAE146 (air mass relative) flight track overlaid.
- High NOx predicted from NYC outflow.
- Obtained using RDF3D trajectories and also accumulating NOx from EDGAR emissions inventory when in ECMWF boundary layer.

Back trajectories calculated from flight track confirm NYC as being at air mass origin

Identifying Lagrangian Opportunities

- Selected out of ~30000 trajs from each domain based on criteria:

1. Passing within range of 2 or 3 bases (*Pease, Azores, Creil*),
2. Accumulated NOx emissions > threshold (*along back trajs*),
3. Further NOx emissions < threshold (*along forward trajs*).

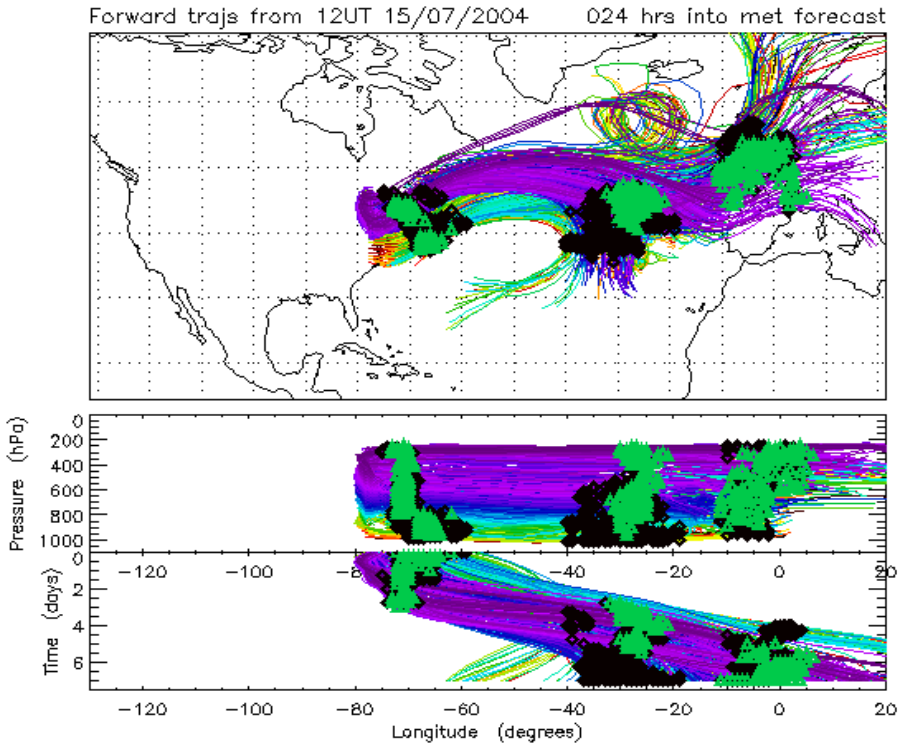
(surface emissions [EDGAR] are picked up within BL as defined by ECMWF forecasts)

Example

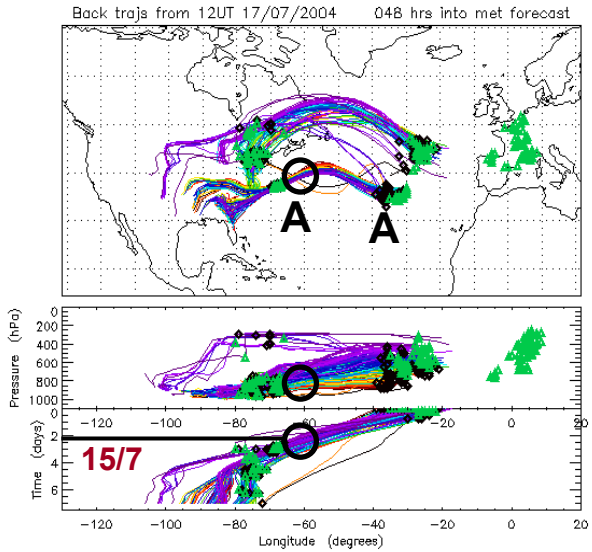
Forward trajs from US domain

Release time 12UT 15 July 2004
Based on ECMWF forecast from 12UT 14 July 2004

- Black diamonds – 2-point opportunities
- Green triangles – 3-point opportunities (US – Azores – Europe)
- Red squares - 3-point opportunities (any other order)

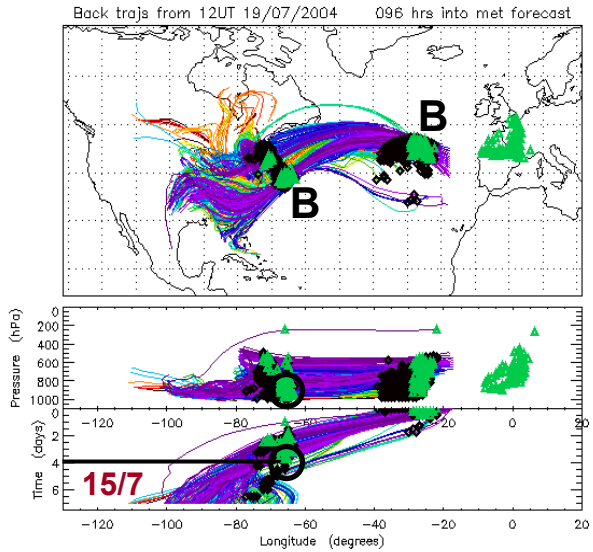


The first Lagrangian opportunities



Back from Azores 12UT **17/7**

Based on ECMWF forecast from 12UT 15/7 **(T+048)**

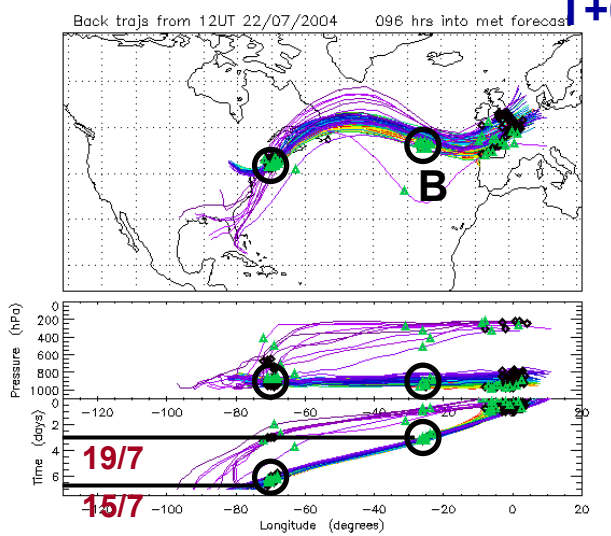


Back from Azores 12UT **19/7**

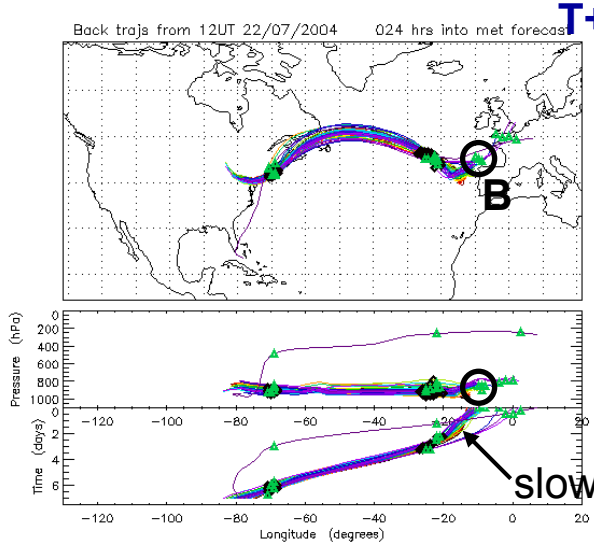
Same met forecast **(T+096)**

Back from Europe 12UT **22/7**

T+096



T+024



Note: Back trajectory calculations use wind *analyses* for dates earlier than start of ECMWF forecast.

Note similarity between trajectory forecasts with different lead times (on right). Air masses are predicted to slow down after Azores in later forecasts.

Sample collection